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Phytoplankton Composition and Distribution in Saginaw Bay

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PHYTOPLANKTON COMPOSITION AND DISTRIBUTION IN SAGINAW BAY

by

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16. ABSTRACT

This summarizes studies conducted during 1980 to assess the effects of reductions in phosphorus loading to Saginaw Bay on phytoplankton in the bay and the adjacent waters of Lake Huron. Quantitative estimates of phytoplankton abundance were developed from an array of stations sampled during the ice-free season. Distribution and abundance of major species and multivariate statistical representations of associations were compared to similar data collected during 1974, prior to phosphorus loading reductions. Results show a substantial reduction in the abundance and range of distribution of eutrophication tolerant and potentially nuisance-producing phytoplankton populations in Saginaw Bay and reduced export of such populations to the main Lake Huron system.

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ABSTRACT

Phytoplankton abundance and species composition in Saginaw Bay in 1980 was highly variable by area. Assemblages sampled ranged from oligotrophic associations similar to those found in the open waters of Lake Huron to those characteristic of the most disturbed regions of the Great Lakes system. Three major regions of influence of the phytoplankton flora are identifiable under average conditions. A number of stations in the southern part of the bay are strongly influenced by loadings from the Saginaw River and maintain high numbers of species characteristic of eutrophic environments. Stations in Wild Fowl Bay and near Oak Point have a different algal association characterized by very high numbers of blue-green algae. It appears that this region is affected by local loadings. Other stations in the bay are more floristically similar, with a transition from more eutrophic associations in the south to oligotrophic associations near the mouth of the bay.

When compared to a similar study conducted during 1974-1976, these results show a substantial improvement of water quality in Saginaw Bay attributable to nutrient loading reductions. The abundance and distribution of blue-green algal populations associated with nuisance conditions has been restricted. Similarly, several species of diatoms associated with extreme water quality degradation in the Great Lakes have decreased to very minor constituents of the flora, where they were previously important. The average cell size of phytoplankton populations in the bay has been significantly reduced.

The reduction in range of distribution of eutrophication tolerant populations has led to less transport of eutrophication tolerant populations from the bay into the open waters of Lake Huron than was the case in 1974-1976. Under 1980 conditions regions of phytoplankton similarity in the bay are clearly related to average current patterns and loading sources. This was not the case in 1974-1976. We interpret this to mean that the phytoplankton component of the Saginaw Bay ecosystem has returned to a more typical function as a result of reduction of grossly excessive phosphorus loadings.

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INTRODUCTION

Saginaw Bay is located on the western side of Lake Huron, extending in a southwesterly direction from the Lake into the lower peninsula of Michigan. Several islands dot the Bay, including the Charity Islands in the center of the Bay and several islands along the eastern shore.

Although there is much spatial and seasonal variability in apparent water quality, it is apparent that Saginaw Bay is one of the most culturally impacted areas of the upper Great Lakes. The historical context of present problems in Saginaw Bay has been reviewed by Freedman (1974). Vollenweider *et al*. (1974) emphasize that certain regions of Saginaw Bay had the highest phytoplankton standing crop and highest rates of productivity found within the Great Lakes system. While such estimates of water quality reflects the high nutrient loading of the Bay, the qualitative composition of the phytoplankton assemblage (Stoermer *et al*., in press) also reflects the high conservative element loadings reported by Beeton *et al*. (1967).

Saginaw Bay is an important source of nutrients and phytoplankton biomass to Lake Huron. The data of Schelske *et al*. (1974) indicate that most of the nutrients discharged into Saginaw Bay are already sequestered by the phytoplankton by the time they reach Lake Huron. Stoermer and Kreis (1980) showed that certain populations derived from Saginaw Bay can survive and be dispersed into Lake Huron.

This study is part of a general investigation of Saginaw Bay and southern Lake Huron. Included in this general investigation are studies of chemical conditions in Saginaw Bay (Smith *et al*. 1977), chemical conditions and productivity in southern Lake Huron (Schelske *et al*. 1977), crustacean zooplankton standing crop (McNaught *et al*. 1980), rotifer standing crop and distribution (Stemberger *et al*. 1979), a general model synthesis of conditions and processes in Saginaw Bay (Bierman and Dolan 1981), and phytoplankton composition and abundance in Lake Huron (Stoermer and Kreis 1980).

The studies cited above deal primarily with conditions in Saginaw Bay and southern Lake Huron prior to extensive nutrient loading reductions to Saginaw Bay accomplished in the late 1970's. This study attempts to measure the qualitative and quantitative response of phytoplankton populations in the bay to reduced nutrient loadings. By using the phytoplankton as an integrated measure of loading effects we hope to be able to detect both the positive effects of nutrient loading reductions and the possible presence of remaining problems in either the general ecology of the bay or local regions within the bay which may require further remedial action. This latter aspect is particularly important in the case of Saginaw Bay, since prior investigations indicate that prior to nutrient loading reductions, substantial portions of the bay were nutrient saturated (Vollenweider *et al*. 1974) or over saturated, resulting in transport of nutrients and algal populations adapted to eutrophic conditions to Lake Huron (Stoermer *et al*. 1980, Stoermer and Kreis 1980).

OBJECTIVES

1. A quantitative assessment of phytoplankton standing stock and composition in Saginaw Bay.
2. Analysis of seasonal and spatial trends of variation in phytoplankton assemblages of Saginaw Bay.
3. Provision of quantitative data for verification of a multi-class phytoplankton model of phytoplankton dynamics in the bay (Bierman and Dolan 1981).

The results pertaining to the first two objectives are reported here. Data generated in support of the third objective will be reported elsewhere (Bierman *et al*. in prep.).

MATERIAL AND METHODS

The basic station array is shown in Figure 1. Stations were selected to provide approximately equal areal coverage of the Bay, except that some bias was given to the region near the mouth of the Saginaw River in terms of station density. Phytoplankton were collected from 1 m depths at each station and, where possible, from 10 m depths. Only 1 m samples were analyzed for this report. Due to occasional bad weather conditions, there were deviations from the planned sampling schedule on some cruises and some stations were not sampled. Such omissions are noted in the discussion of the appropriate data

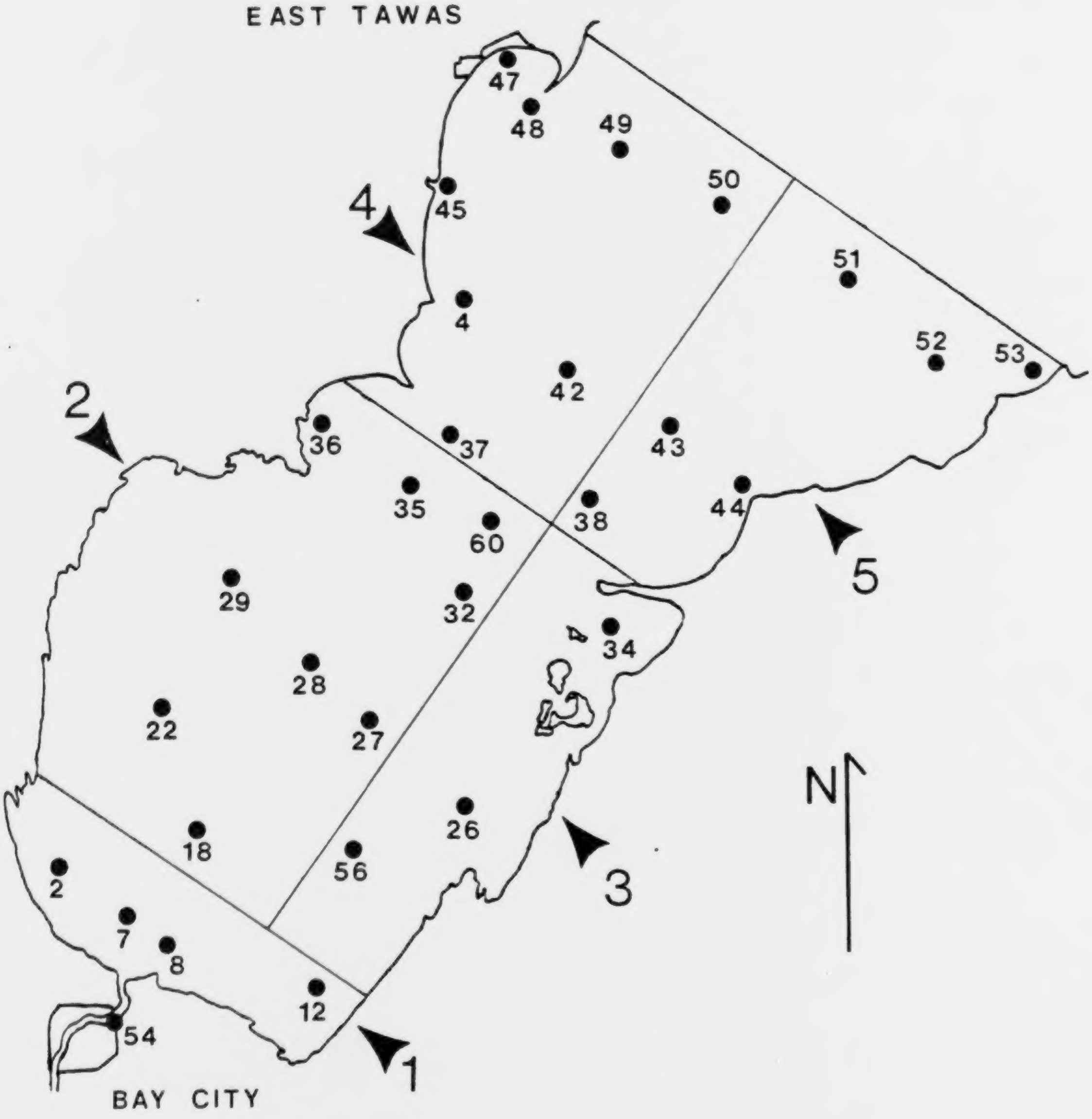
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Figure 1. Station locations in Saginaw Bay for this study. Segments 1-5 were previously defined by Bratzel _et al_. (1977).

analyses. Eleven cruises were made from April 1980 through November 1980 (Table 1).

Samples at all stations were taken as splits from a single 8 liter Niskin bottle cast. Immediately after collection, approximately 100 mls of sample were fixed with 2 mls of 50% electron microscope grade gluteraldehyde and placed on ice for transportation to the laboratory for further processing. Depending on the density of suspended material in the sample, between 5 and 50 mls was withdrawn after gentle agitation to resuspend the phytoplankton. The suspension was concentrated by filtration onto 25 mm "AA" Millipore filters, which was then partially dehydrated through an ethanol series, embedded in clove oil on 50 x 75 mm glass slides, covered with a 43 x 50 mm #1 thickness cover slip and allowed to clear for approximately two weeks. The finished mounts were examined on a Leitz Ortholux microscope fitted with bright field optics at a magnification of approximately 1200x. Populations estimates are given for the averaged counts of two transects of 10 mm corrected for the volume filtered and the area of the filter pad examined.

RESULTS

BAY-WIDE SUMMARY

The overall abundance of phytoplankton at all stations in all cruises sampled during the study is shown in Table 2. Total average cell abundance is high but there is a wide variation in the distribution of cell counts among taxonomic groups. Blue-greens, diatoms and greens were the dominant taxa. Cryptomonads, chrysophytes and undetermined flagellates were present at all stations but comprised a smaller portion of the average total assemblage.

TABLE 1. CRUISE DATES FOR 1980 SAMPLING SEASON ON SAGINAW BAY

Cruise No.	Dates
83	14-18 April
84	5- 9 May
86	26-30 May
87	16-20 June
88	7-11 July
90	28 July - 1 August
91	18-22 August
92	8-12 September
93	29 September - 3 October
94	20-24 October
95	10-14 November

TABLE 2. SUMMARY OF SAGINAW BAY PHYTOPLANKTON DENSITIES BY MAJOR TAXONOMIC GROUP

Taxon	Average cells/mL	Relative Abundance of Assemblage (%)
Blue-greens	6,652.4	42.7
Diatoms	3,843.9	25.1
Greens	3,698.2	24.1
Cryptomonads	469.2	3.1
Chrysophytes	340.9	2.2
Undetermined flagellates	310.9	2.0
Dinoflagellates	14.8	0.1
Euglenophytes	0.4	<0.1
Total	15,330.7	

Dinoflagellates and euglenoids were a minor portion of the total assemblage, never occurring in abundance.

Seasonal abundance of the total phytoplankton is shown in Figure 2. There was a steady increase in abundance from the first sampling period in April through the September sampling. Abundance declined through October and November. In April, diatoms are the dominant group, but green algae become the most abundance division by June (Figure 3). Thereafter, until the period following the late summer maximum, blue-green algae dominate the assemblage. In late fall diatoms reach their maximum abundance and are again the dominant group (Figure 3). Only in late fall and early spring are chrysophytes, cryptomonads and undetermined flagellates relatively abundant (Figure 4). In terms of absolute abundance, each of these three groups have an early spring maximum and a second maximum near the total phytoplankton maximum. Dinoflagellates exhibit both a spring and late summer pulse, and are a persistent but minor component of the assemblage through all seasons. Euglenophytes occur only sporadically (Figure 5).

SEGMENT ANALYSIS

Analysis of phytoplankton abundance by Bay segments designated by Bratzel _et_ _al_. (1977) gives some insight into processes controlling phytoplankton abundance and distribution in Saginaw Bay (see Figure 1). Bratzel _et_ _al_. (1977) based this segmentation scheme in part on average current patterns in the Bay. Waters of Lake Huron usually enter from the northwest corner of the Bay, travel down the western shore and receive significant nutrient input at the Saginaw River, move up the eastern shore and exit into Lake Huron at the northeastern corner of Saginaw Bay. In general, total phytoplankton

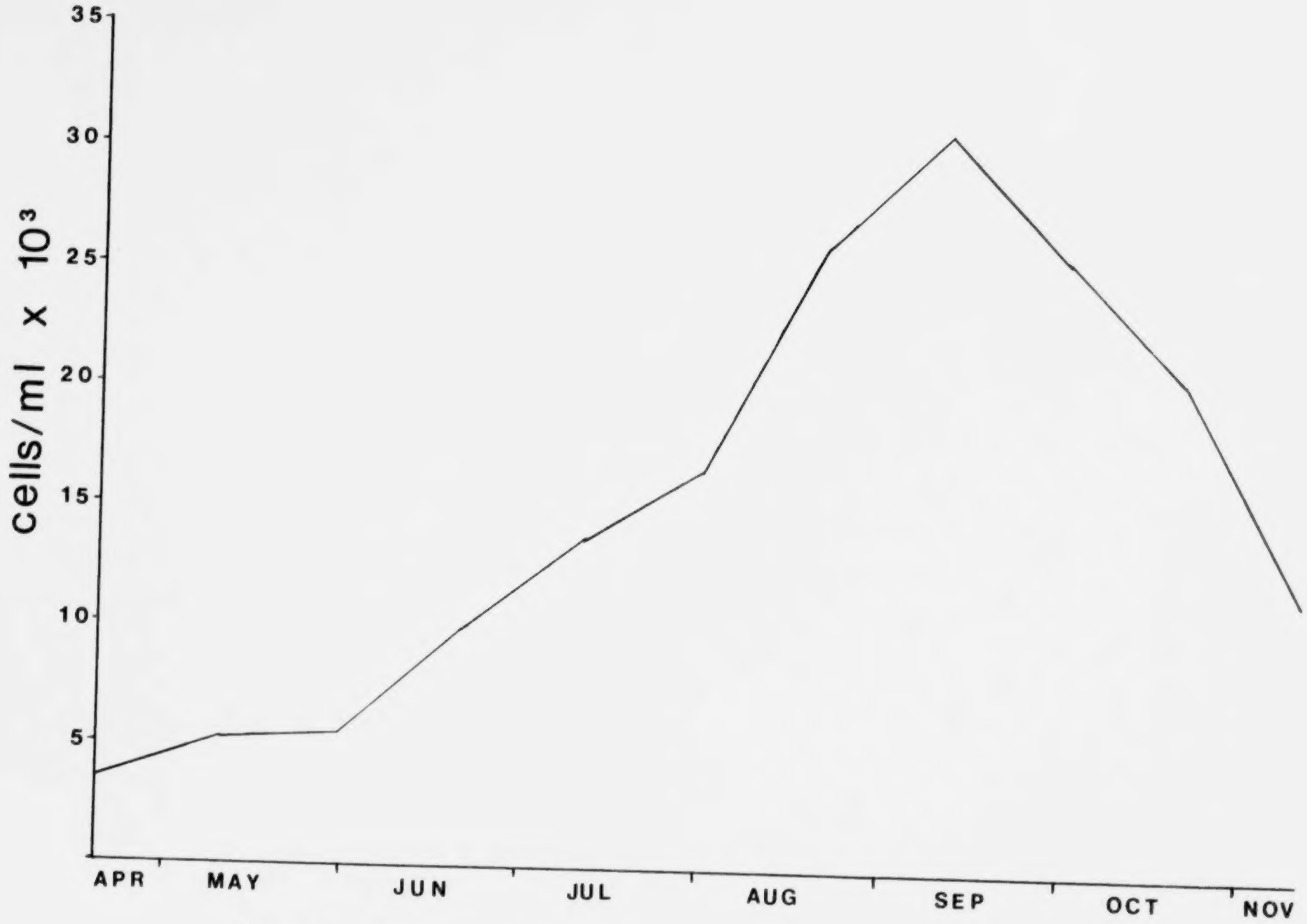


Figure 2. Seasonal variation of total cell abundance in Saginaw Bay.

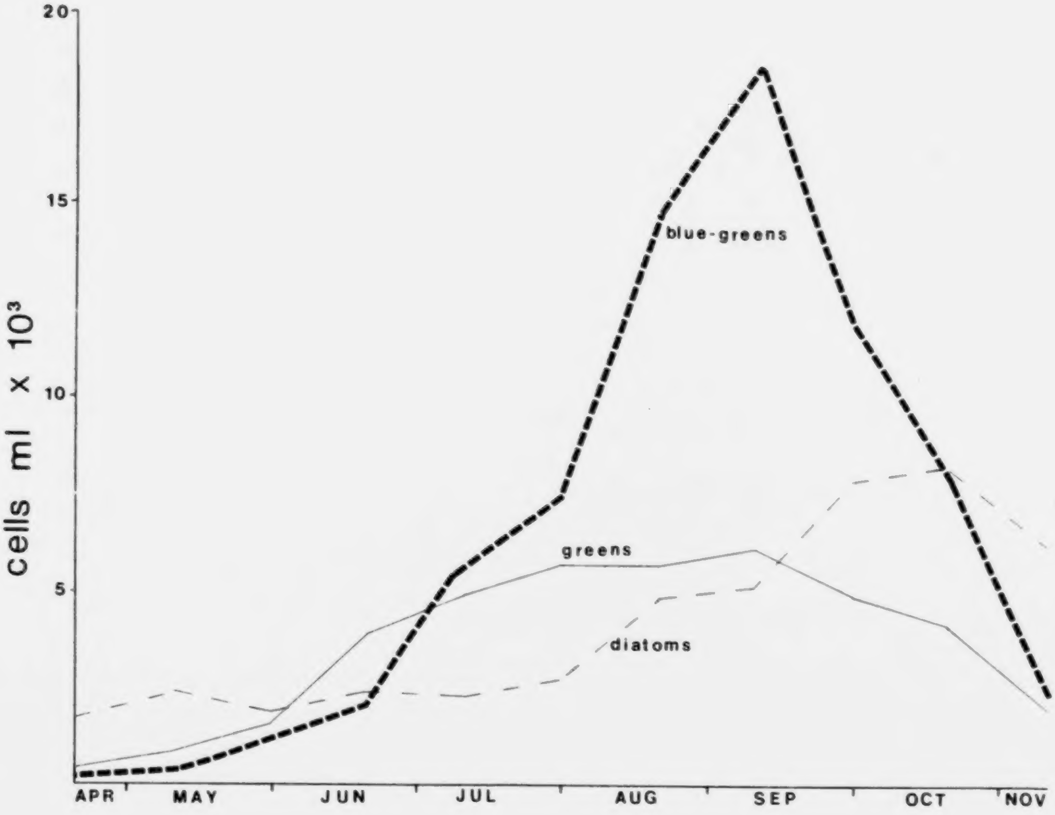


Figure 3. Seasonal variation of abundance of the three dominant algal divisions in Saginaw Bay.

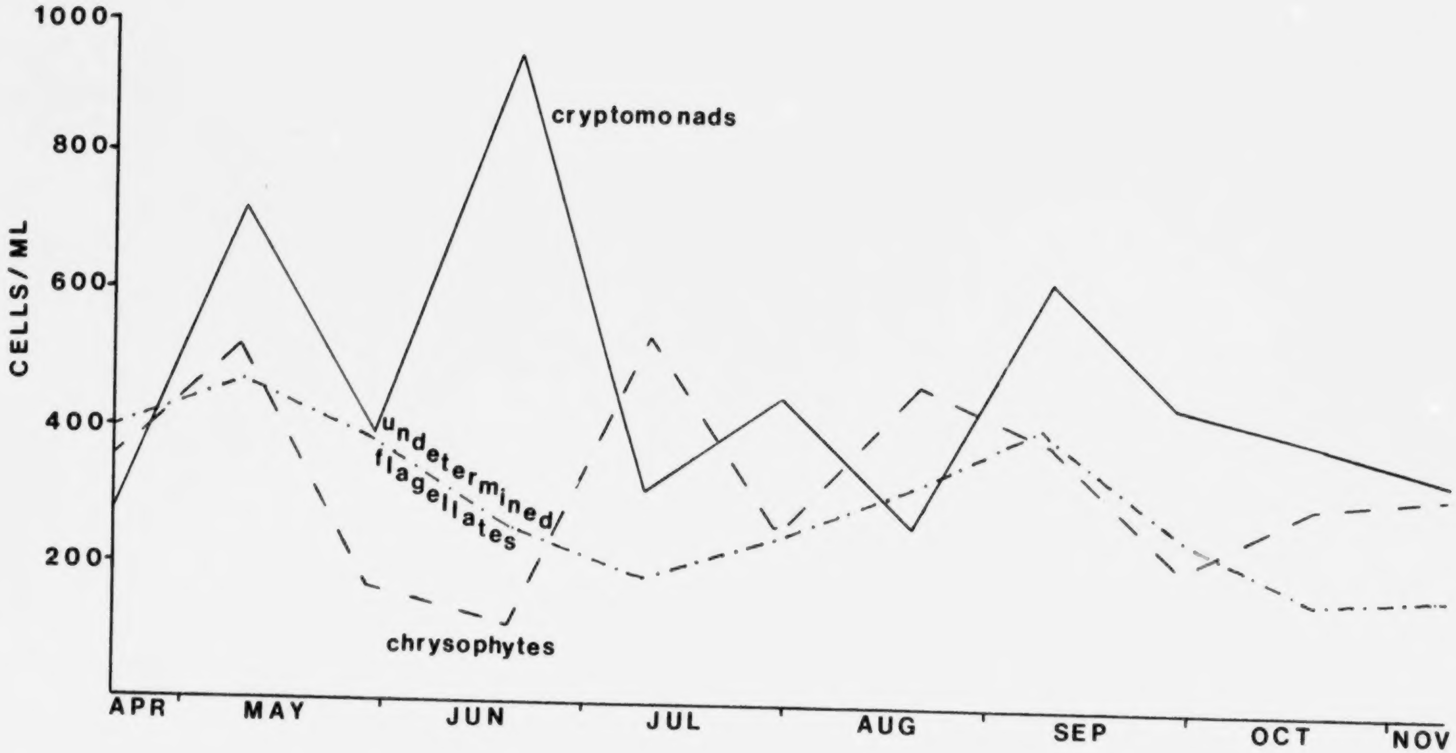


Figure 4. Seasonal abundance of the three subdominant algal divisions in Saginaw Bay.

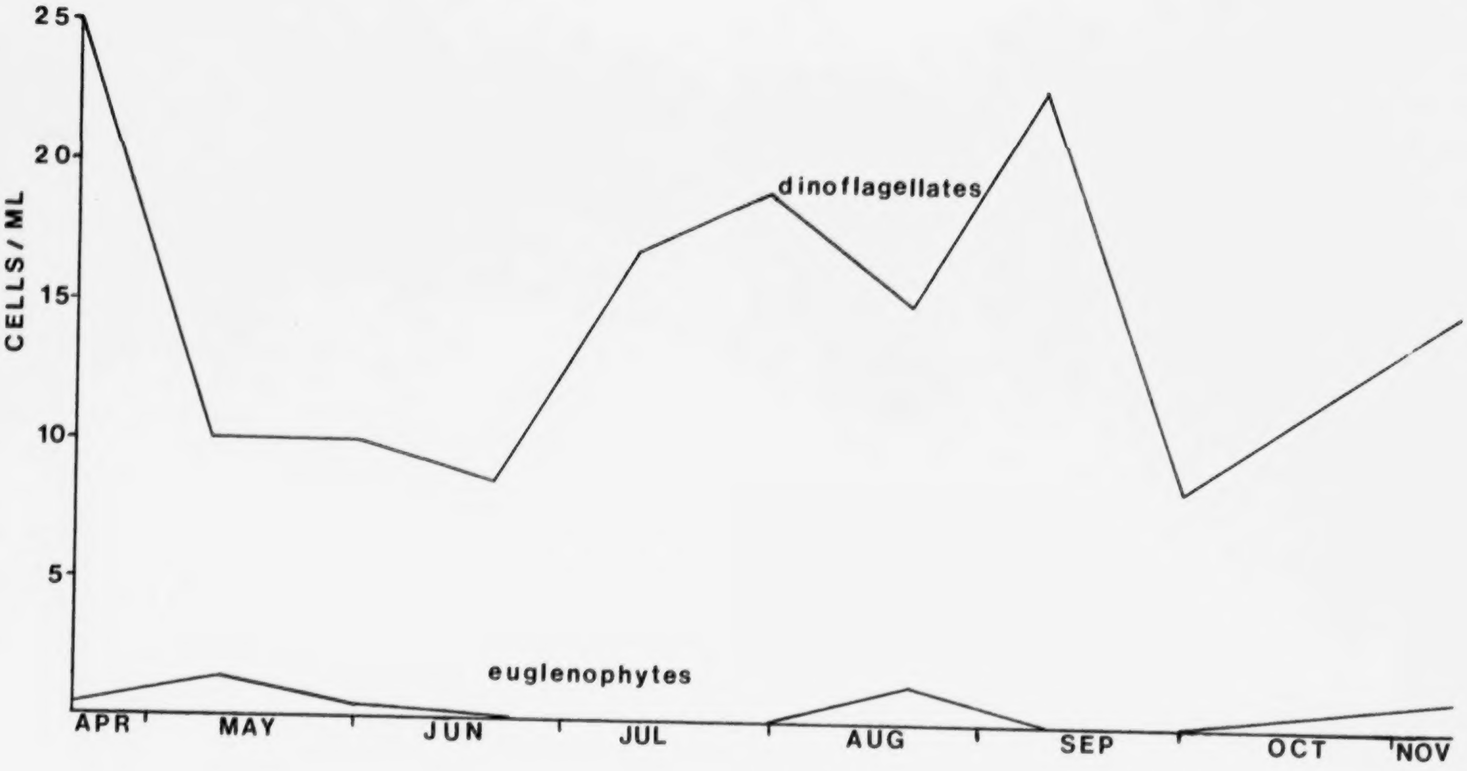


Figure 5. Seasonal abundance of minor algal divisions in Saginaw Bay.

abundances by segment support the hypothesis. Cell densities increase from segment 4 to segment 2 to segment 1, reach a maximum at segment 3, and then decrease at segment 5 (Table 3).

Differences in cell densities for stations in each of the segment pairs, in the order given, are statistically significant except for the pair of segments 1 and 3 (Table 4). Stations in segment 3 have significantly higher cell densities than stations in segment 2. The difference between segments 4 and 5 is not statistically significant, even though the abundance average of segment 4 is approximately twice that of 5. This indicates that segment 5 is heterogenous group of stations with varying levels and sources of control of phytoplankton abundance. This contention will be more fully explored in the section entitled "Community Analysis."

The absolute abundance of the major divisions of algae by segment over all cruises is shown in Table 3. Blue-green algae are dominant in segments 1, 3, and 5 and diatoms are dominant in segments 2 and 4. Chrysophytes, cryptomonads and undetermined flagellates tend to be most abundant in the three inner bay segments but reach their highest relative abundance at segment 4 (Table 3). Dinoflagellates and euglenophytes were minor components of the assemblage at all segments except that euglenophytes were entirely absent from segment 5.

All segments reached peak abundance of total phytoplankton in late August to early September (Figure 6). Abundance levels increased more or less gradually to summer maxima in all segments. Abundance levels in segments 2 and 5 were less stable than the other three segments during the summer bloom (Figure 6), indicating that important local effects on phytoplankton populations of these areas may not be quickly integrated with the rest of the bay.

TABLE 3. AVERAGE ABSOLUTE ABUNDANCE (CELLS/ML) OF ALGAL DIVISIONS BY SEGMENT

Abbreviations: N, total number of samples per segment; TP, Total Phytoplankton; BG, Blue-Green; GR, Green algae; DI, Diatoms; CH, Chrysophytes; CR, Cryptomonads; UNDET., Undetermined flagellates; DN, Dinoflagellates; EU, Euglenophytes

Segment	N	TP	BG	GR	DI	CH	CR	UNDET	DN	EU
1	48	24,355	8,754	8,270	5,707	423	724	457	19	1.5
2	90	11,023	2,688	2,670	4,467	348	611	227	12	0.1
3	30	45,888	30,401	8,978	5,057	423	475	526	28	0.6
4	64	4,359	1,058	534	2,021	265	208	262	11	0.0
5	37	8,304	4,990	1,462	2,080	283	241	235	14	-

TABLE 4. RESULTS OF KRUSKAL-WALLIS TEST FOR COMPARISONS OF ADJACENT SEGMENTS

Significance levels = *$p<0.05$; **$p<0.01$; ***$p<0.001$. N.S. = not significant

Segment Pairs	Kruskal-Wallis Statistic
1-2	24.269***
1-3	1.866 N.S.
2-3	20.060***
2-4	42.347***
3-5	28.987***
4-5	1.611 N.S.

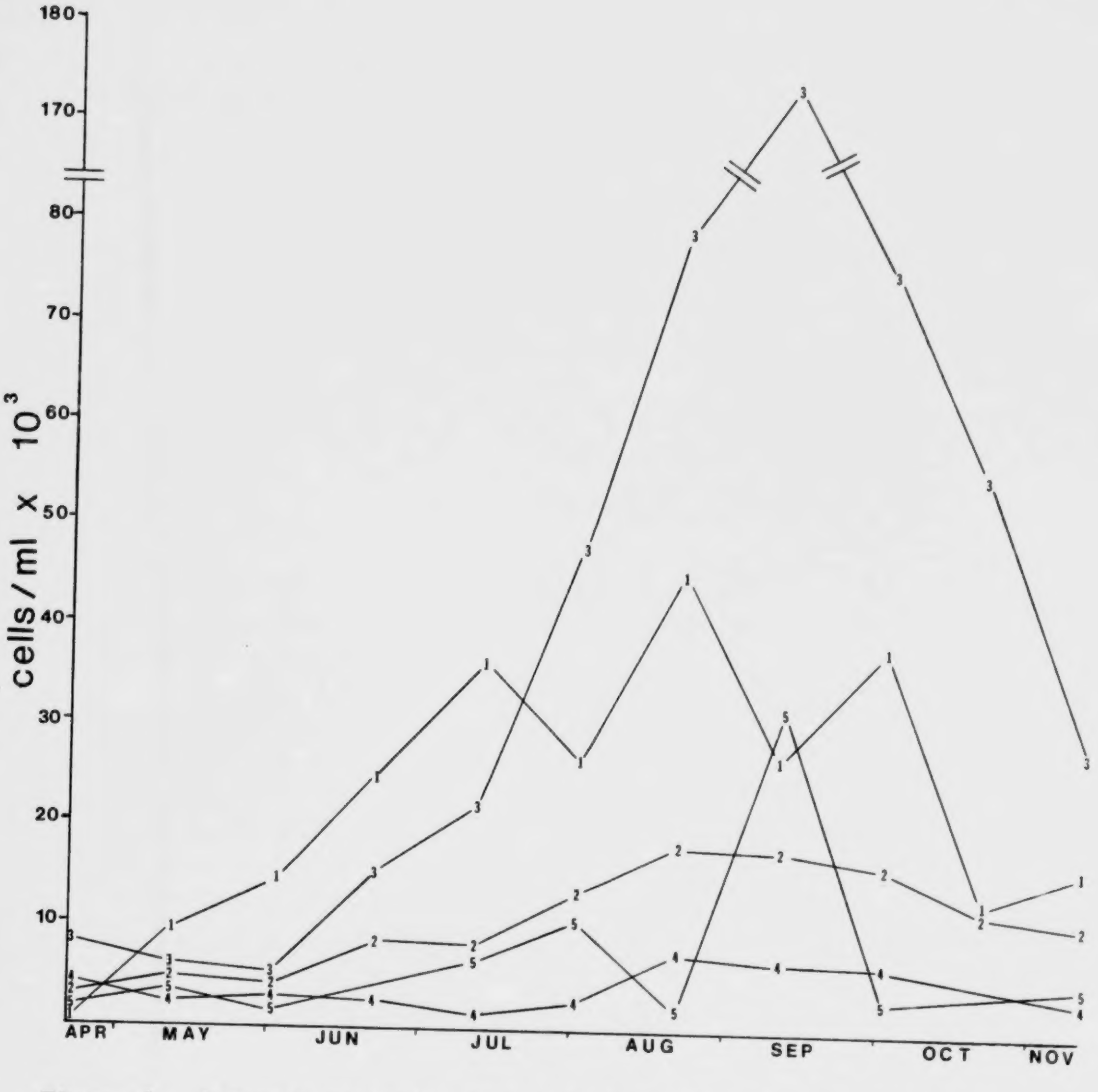


Figure 6. Seasonal variation in total phytoplankton abundance by segment in Saginaw Bay.

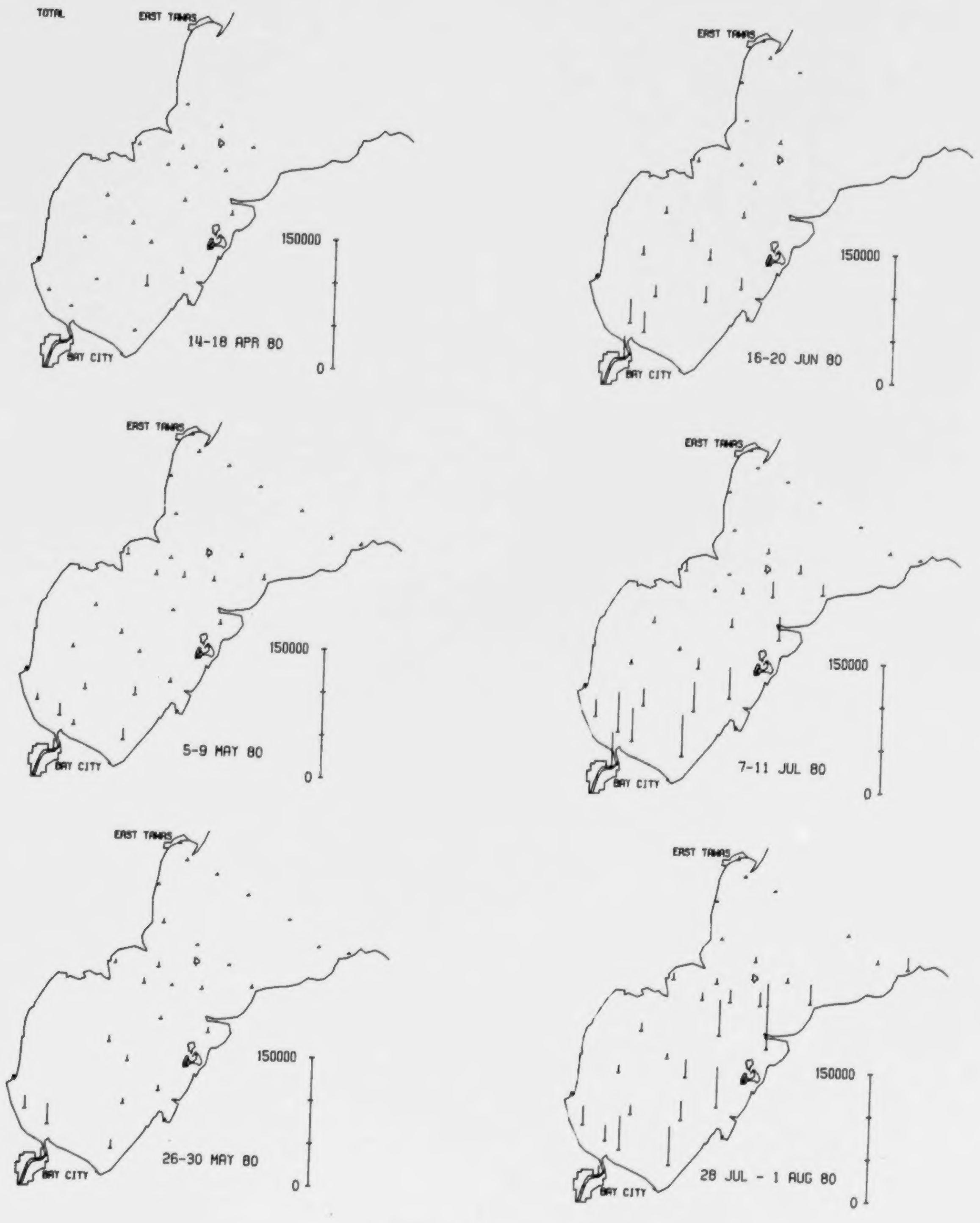
THE PHYTOPLANKTON FLORA OF SAGINAW BAY

A summary compilation of the taxa occurring in samples taken during this study are given in Appendix 1. In many cases, taxa were encountered which could not be identified with known species. In some cases, this was due to the lack of critical life cycle stages or structures necessary for identification. In other cases, it was probably due to the availability of only a limited number of specimens atypical of known species. Lastly, there were undoubtedly specimens which belong to undescribed taxa. Specimens were identified to the lowest possible taxonomic level, usually the species level, but occasionally only generic affinity could be confidently determined. If generic determination could not be made, then specimens were placed in the appropriate division under some descriptive term, e.g. undetermined blue-green filament.

In the rest of this section, seasonal and spatial trends of representative taxa of each of the major taxonomic groups are illustrated and discussed. Not only taxa with seasonal and spatial trends corresponding with general trends, but also taxa with distributions exceptional to general trends, were selected for study.

Total Phytoplankton (Figure 7)

Total abundance is uniform in all areas of the Bay from April through May. Populations begin to increase in the inner Bay by June, but cell densities in the outer Bay remain low. In July, cell densities begin to increase in the outer Bay, but mainly only in nearshore areas between Wild Fowl Bay and Port Austin. From late July through August, abundances increase steadily in all areas with maximum densities occurring at inner Bay stations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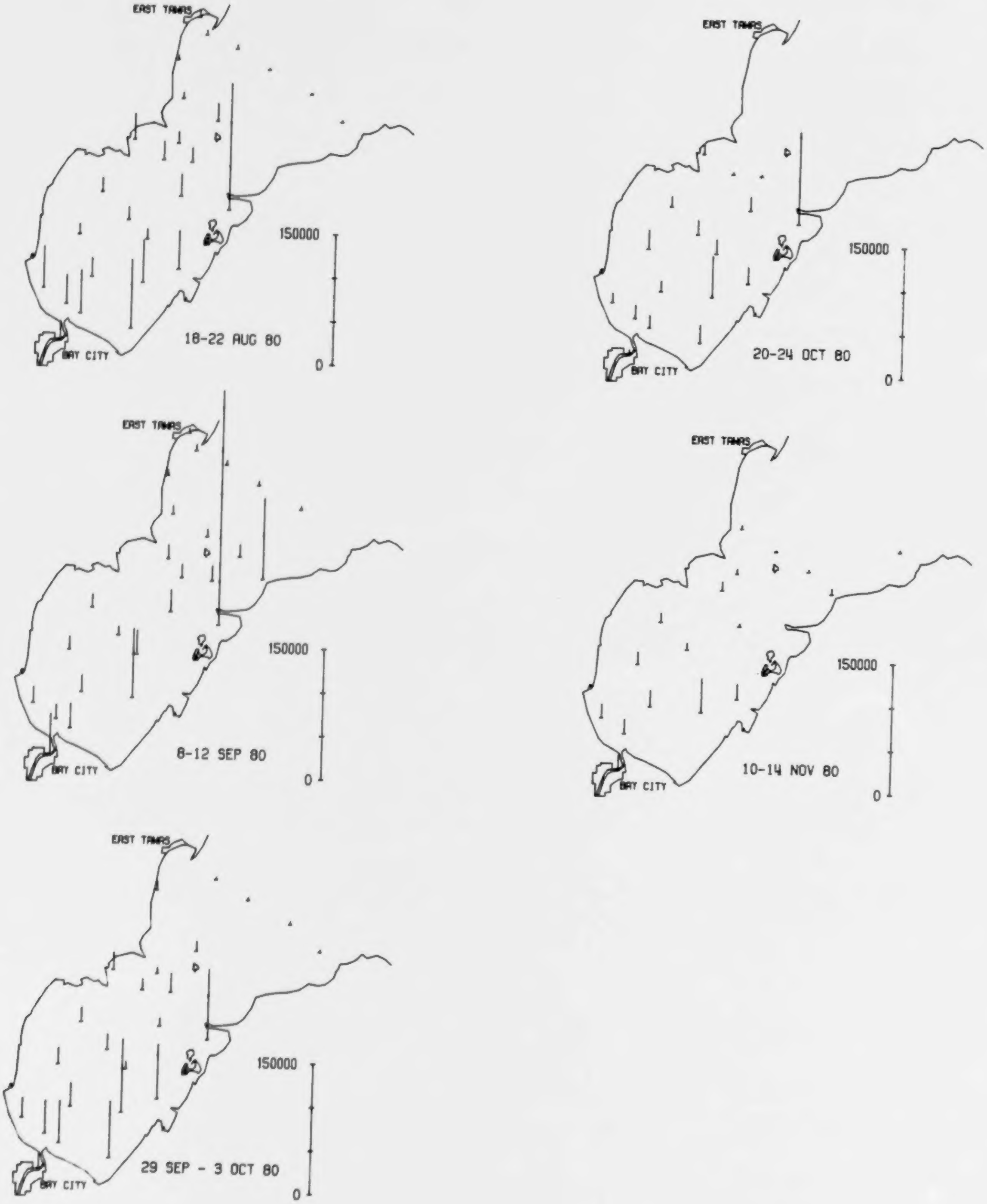
5-9 MAY 80
7-11 JUL 80
26-30 MAY 80
28 JUL - 1 AUG 80

Figure 7. Distribution of total phytoplankton.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20-24 OCT 80
8-12 SEP 80
10-14 NOV 80
29 SEP - 3 OCT 80

Figure 7. (continued).

near the mouth of the Saginaw River and along the eastern shore between the Quaniccassee River and Wild Fowl Bay. Total abundance levels then stabilize through early October. Exceptions occur at Wild Fowl Bay and at Oak Point, where significant blooms occur in September. Cell densities decline at all stations from late September-early October through November.

Cyanophyta or Blue-green algae (Figure 8)

Most species of this division are associated with eutrophic to highly eutrophic waters. Many, if not all, species are capable of nitrogen fixation and so are at an advantage when other algae are nitrogen limited. This situation occurs in many eutrophic lakes in mid- to late-summer following diatom and green algae blooms. During this period blue-greens typically reach their greatest abundance. In Saginaw Bay, blue-green abundance steadily increased from late May through September. Highest levels were reached in the eastern half of the inner Bay, especially at Wild Fowl Bay in September. Blue-green algae are largely absent from the outer Bay, except for nearshore stations such as Oak Point (Station 44, Figure 1). Significant populations develop here and in the shallow waters surrounding Charity Island in July, August, and September.

Blue-green filament #3 (Figure 9)

Taxonomic affinities of this taxon and blue-green filament #4 are uncertain but they both may be conspecific with *Aphanizomenon gracile*. The areal distribution of blue-green filament #3 is highly restricted in Saginaw Bay. It occurs in nearshore areas of the inner Bay and reaches its maximum abundance in Wild Fowl Bay in August and September.

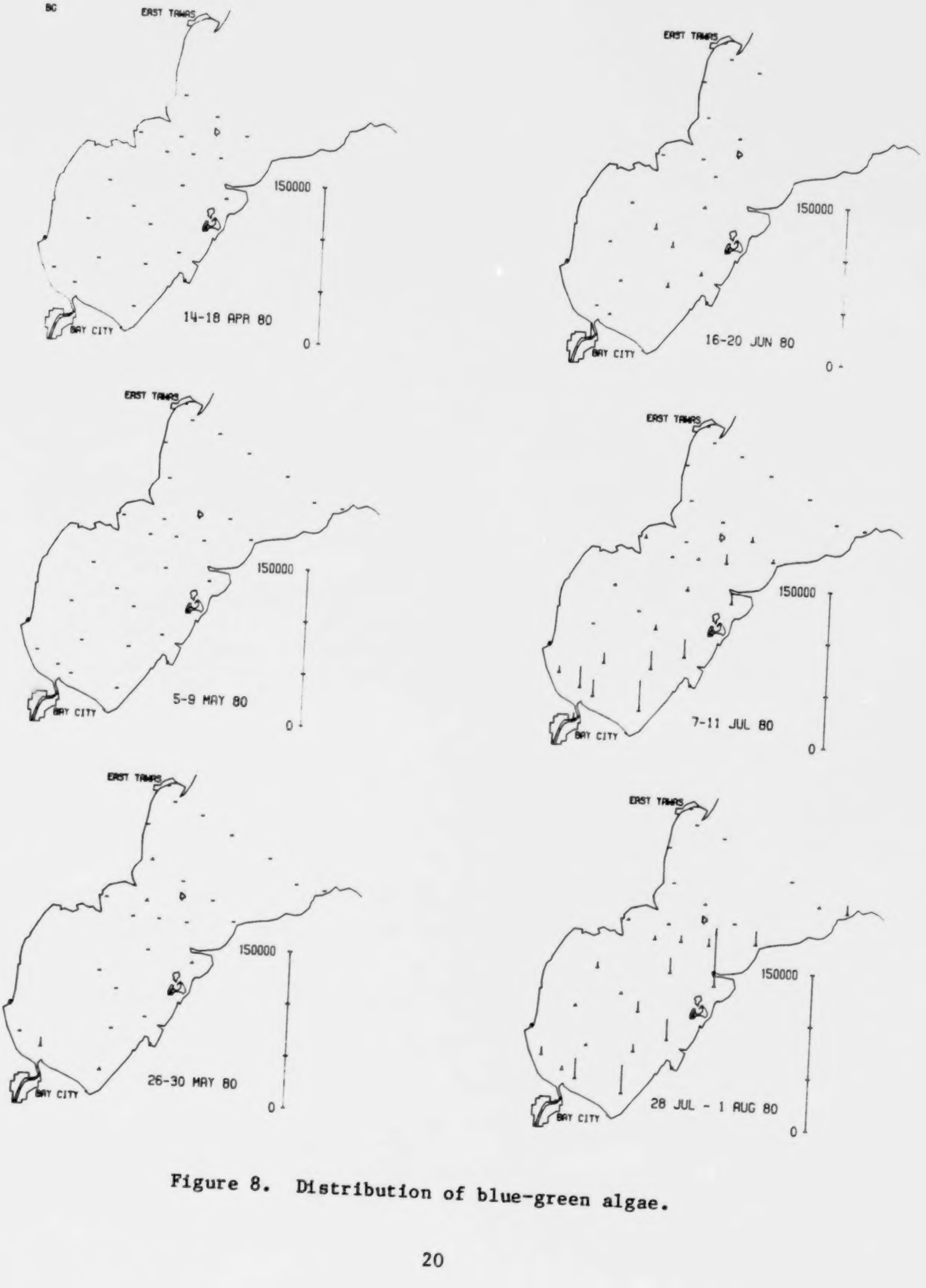
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Figure 8. Distribution of blue-green algae.

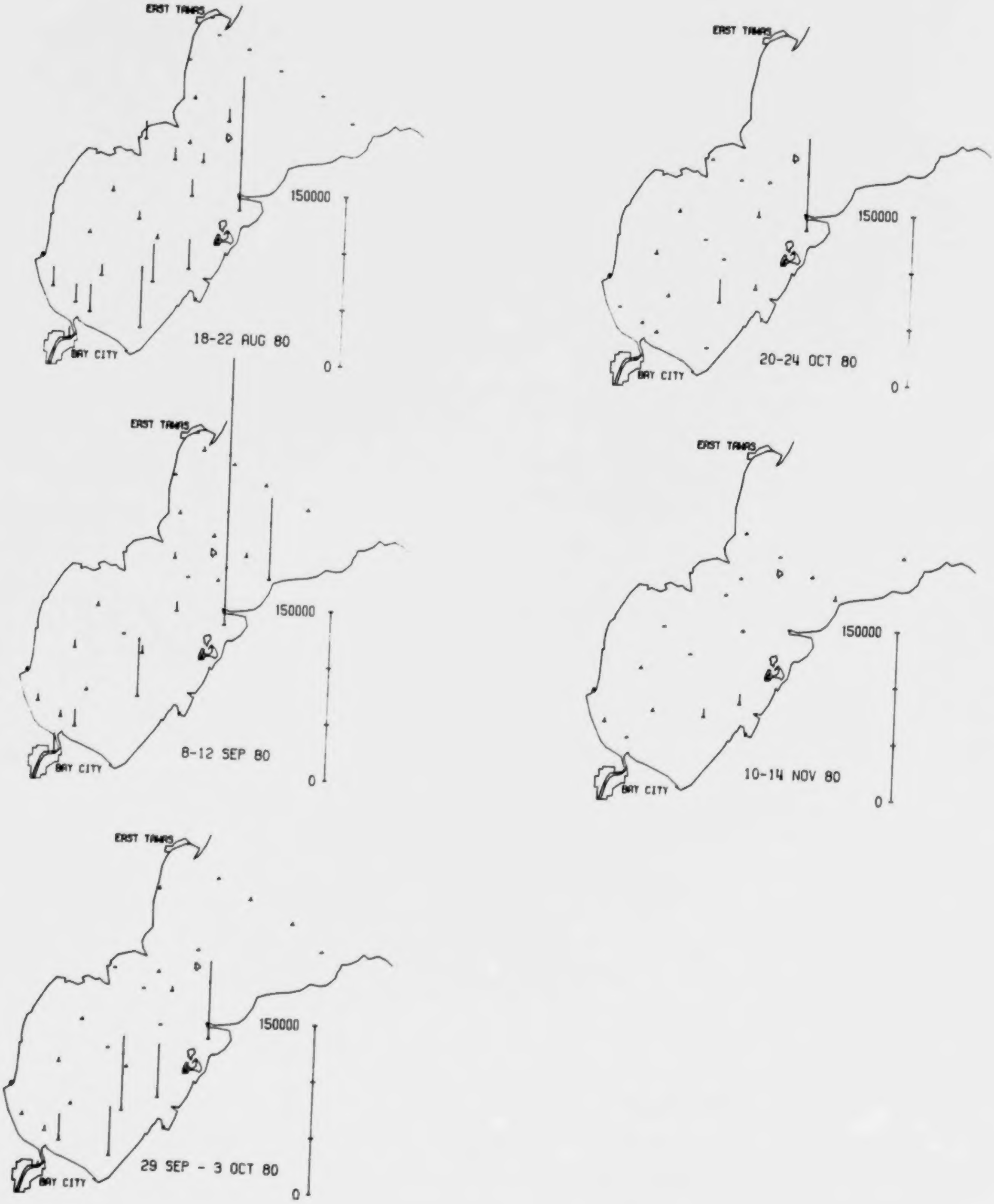
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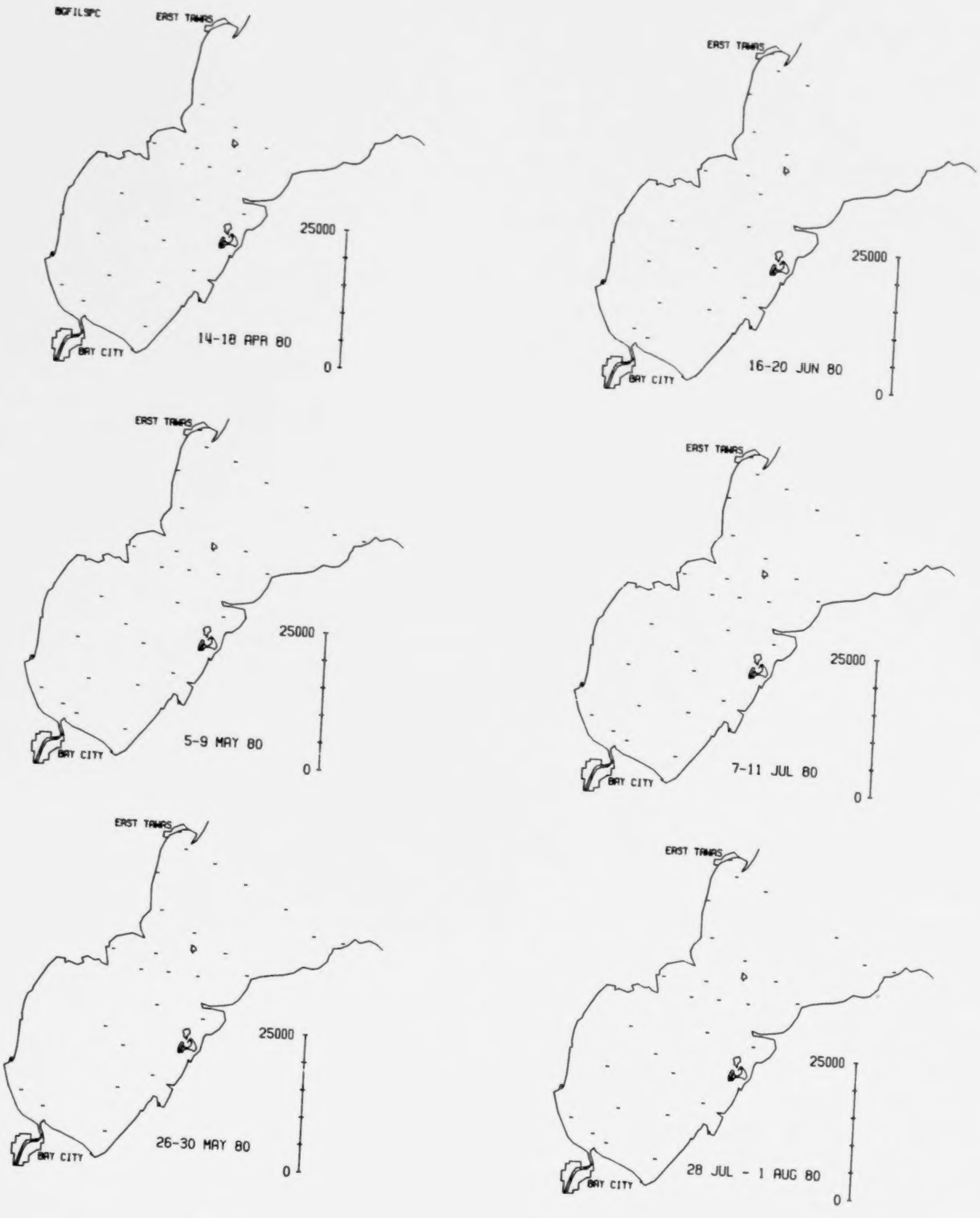
Figure 8. (continued).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14-18 APR 80
EAST TAWAS
25000
0
BAY CITY
16-20 JUN 80
EAST TAWAS
25000
0
BAY CITY
5-9 MAY 80
EAST TAWAS
25000
0
BAY CITY
7-11 JUL 80
EAST TAWAS
25000
0
BAY CITY
26-30 MAY 80
EAST TAWAS
25000
0
BAY CITY
28 JUL - 1 AUG 80

Figure 9. Distribution of blue-green filament #3.

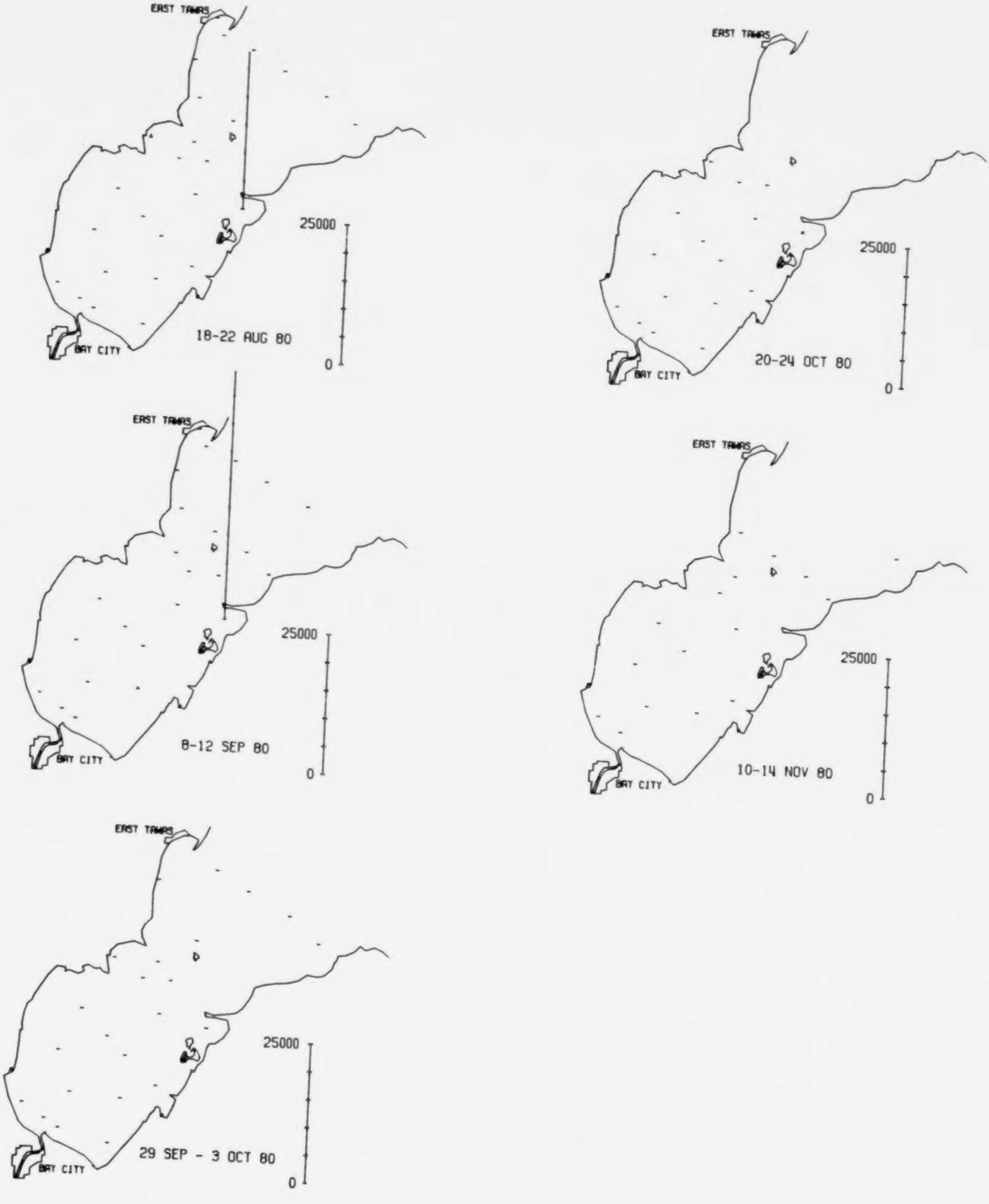

EAST TAWAS
BAY CITY
25000
0
18-22 AUG 80
20-24 OCT 80
8-12 SEP 80
10-14 NOV 80
29 SEP - 3 OCT 80

Figure 9. (continued).

Blue-green filament #4 (Figure 10)

This taxon is somwhat more widely distributed than blue-green filament #3, but shares its strong association with nearshore areas. Like blue-green filament #3 and several other blue-green filamentous species, it first occurs in significant numbers in August. Its maximum abundance occurs in September when a large pulse occurs at Wild Fowl Bay, and moderate levels also develop at Oak Point. During August and September, it is also abundant at stations near the Quaniccassee River. Numbers decline in all areas from late September through November.

Anabaena flos-aquae (Figure 11)

This species is a common minor component of phytoplankton assemblages of offshore waters in the Great Lakes, but reaches its highest abundances in eutrophic areas (Stoermer 1978). It is a heterocyst-forming blue-green and so is capable of significant nitrogen fixation even in the presence of oxygen. Its distribution in Saginaw Bay is somewhat atypical of other blue-green algae in that moderate populations develop in May and that moderate to high cell densities occurred in middle and outer Bay waters. High populations first develop nearshore, but by June high cell densities are found at offshore mid-Bay stations. It was then generally absent in early July, but reoccurred in late July when maximal population levels developed along the western shore.

Anacystis cyanea (Figure 12)

This species is common, and occasionally forms nuisance blooms, in small eutrophic lakes. It is rare in the Great Lakes except in highly eutrophic

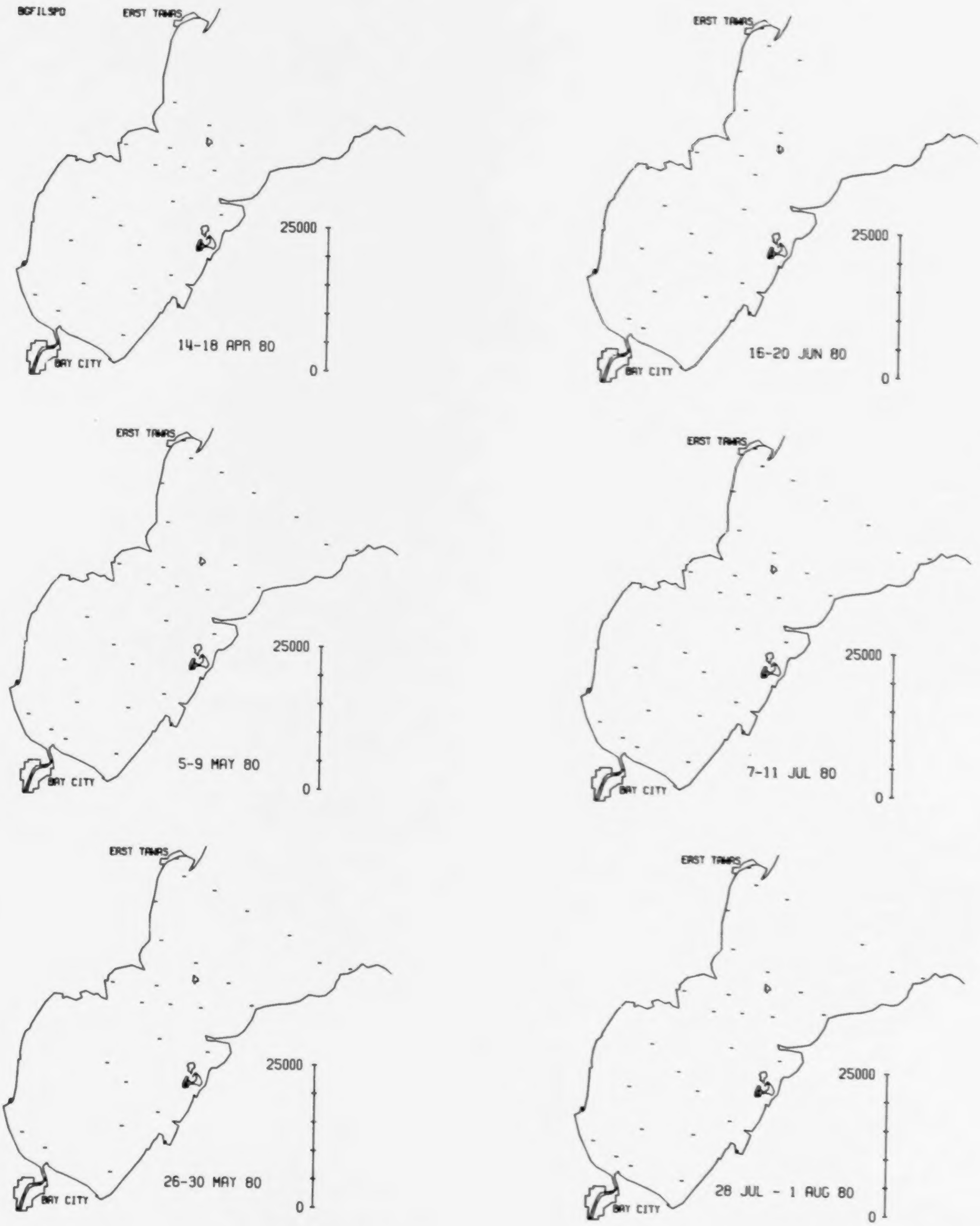

BGFILSPD
EAST TAWAS
BAY CITY
25000
0
14-18 APR 80
16-20 JUN 80
5-9 MAY 80
7-11 JUL 80
26-30 MAY 80
28 JUL - 1 AUG 80

Figure 10. Distribution of blue-green filament #4.

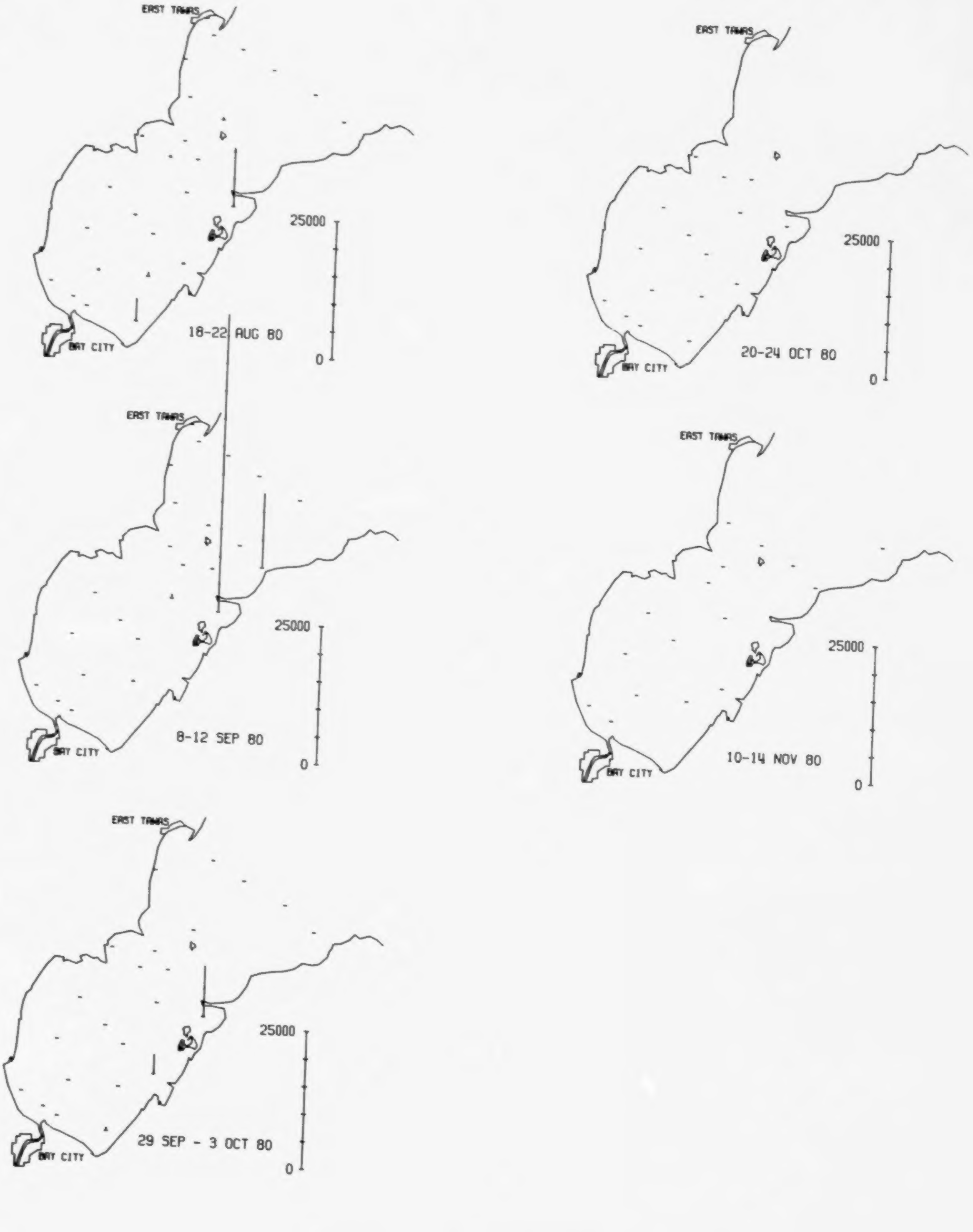

EAST TAWAS
BAY CITY
25000
0
18-22 AUG 80
EAST TAWAS
BAY CITY
25000
0
20-24 OCT 80
EAST TAWAS
BAY CITY
25000
0
8-12 SEP 80
EAST TAWAS
BAY CITY
25000
0
10-14 NOV 80
EAST TAWAS
BAY CITY
25000
0
29 SEP - 3 OCT 80

Figure 10. (continued).

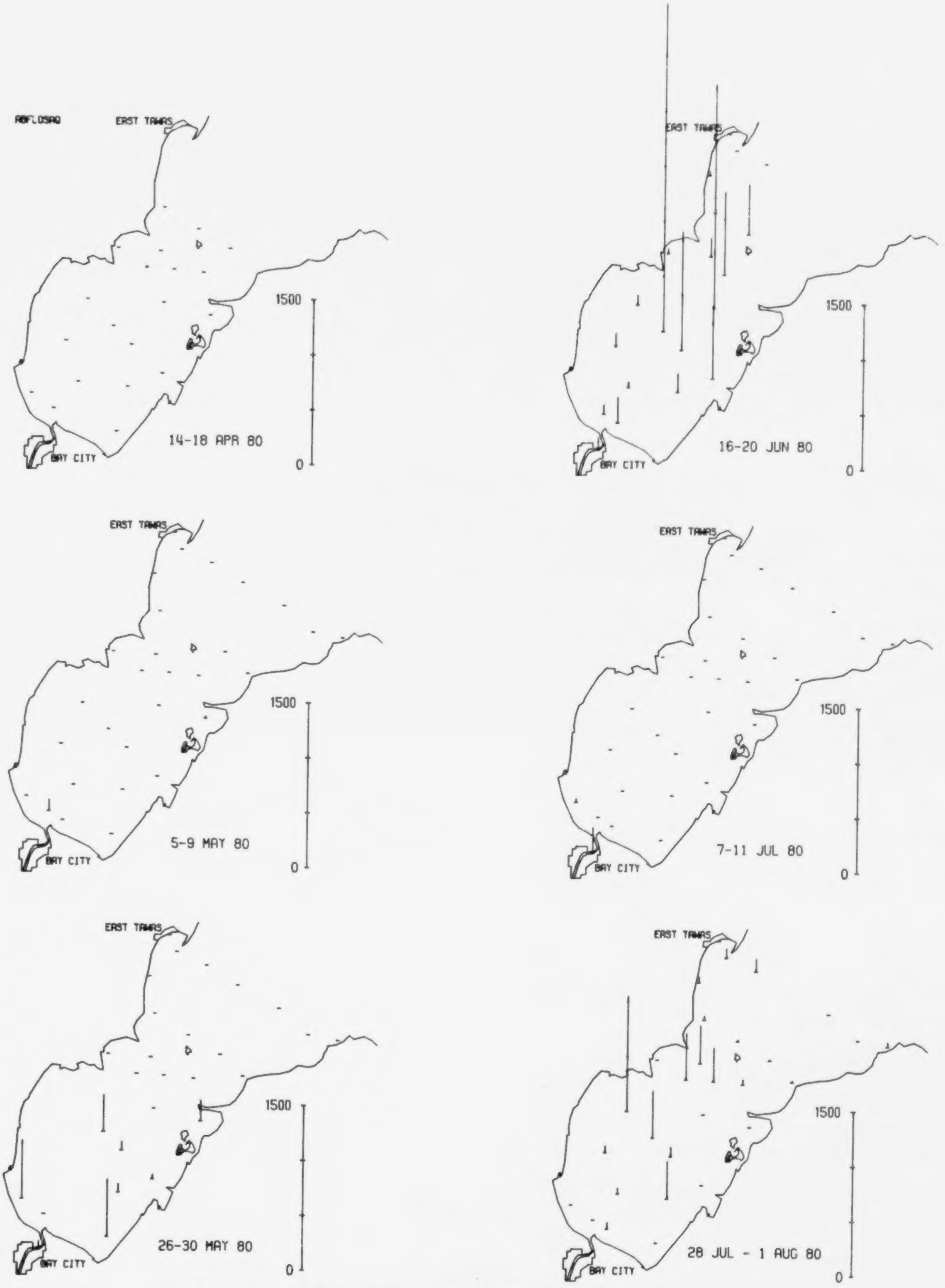

AAFLOSAQ
EAST TAWAS
BAY CITY
1500
0
14-18 APR 80
EAST TAWAS
BAY CITY
1500
0
16-20 JUN 80
EAST TAWAS
BAY CITY
1500
0
5-9 MAY 80
EAST TAWAS
BAY CITY
1500
0
7-11 JUL 80
EAST TAWAS
BAY CITY
1500
0
26-30 MAY 80
EAST TAWAS
BAY CITY
1500
0
28 JUL - 1 AUG 80

Figure 11. Distribution of Anabaena flos-aquae.

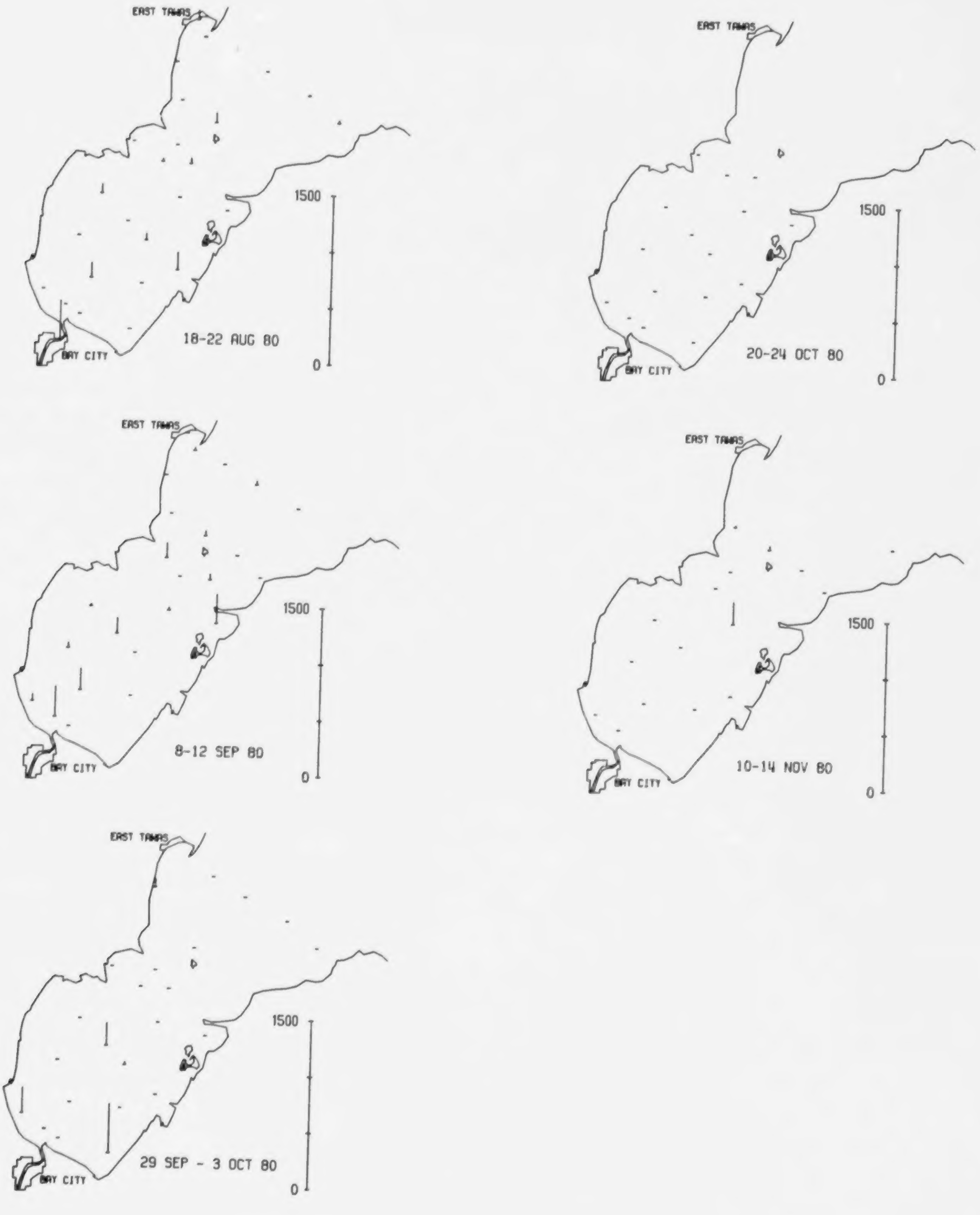

EAST TAWAS
BAY CITY
1500
0
18-22 AUG 80
EAST TAWAS
BAY CITY
1500
0
20-24 OCT 80
EAST TAWAS
BAY CITY
1500
0
8-12 SEP 80
EAST TAWAS
BAY CITY
1500
0
10-14 NOV 80
EAST TAWAS
BAY CITY
1500
0
29 SEP - 3 OCT 80

Figure 11. (continued).

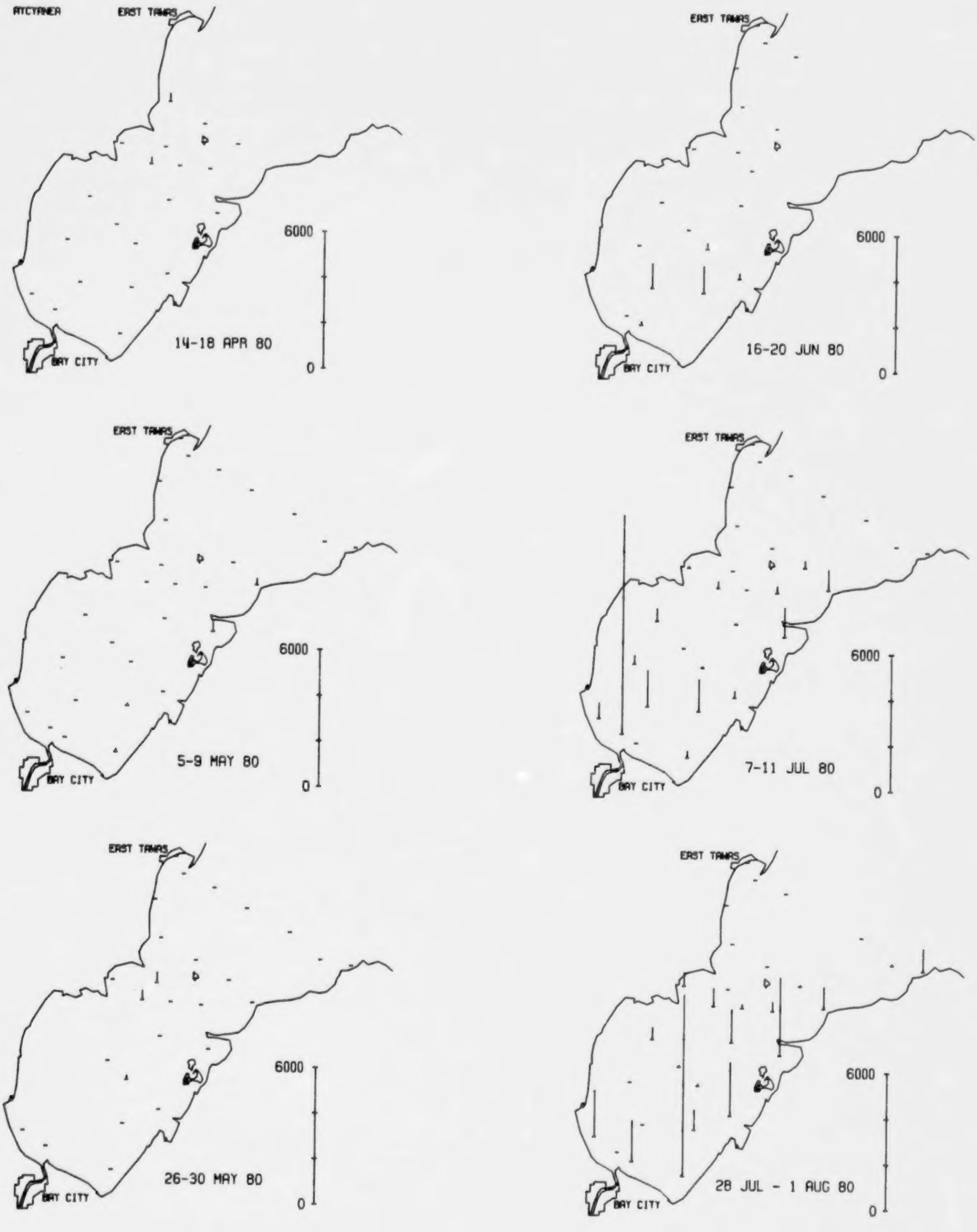

ATCYANEA
EAST TAWAS
6000
14-18 APR 80
0
BAY CITY
EAST TAWAS
6000
16-20 JUN 80
0
BAY CITY
EAST TAWAS
6000
5-9 MAY 80
0
BAY CITY
EAST TAWAS
6000
7-11 JUL 80
0
BAY CITY
EAST TAWAS
6000
26-30 MAY 80
0
BAY CITY
EAST TAWAS
6000
28 JUL - 1 AUG 80
0
BAY CITY

Figure 12. Distribution of Anacystis cyanea.

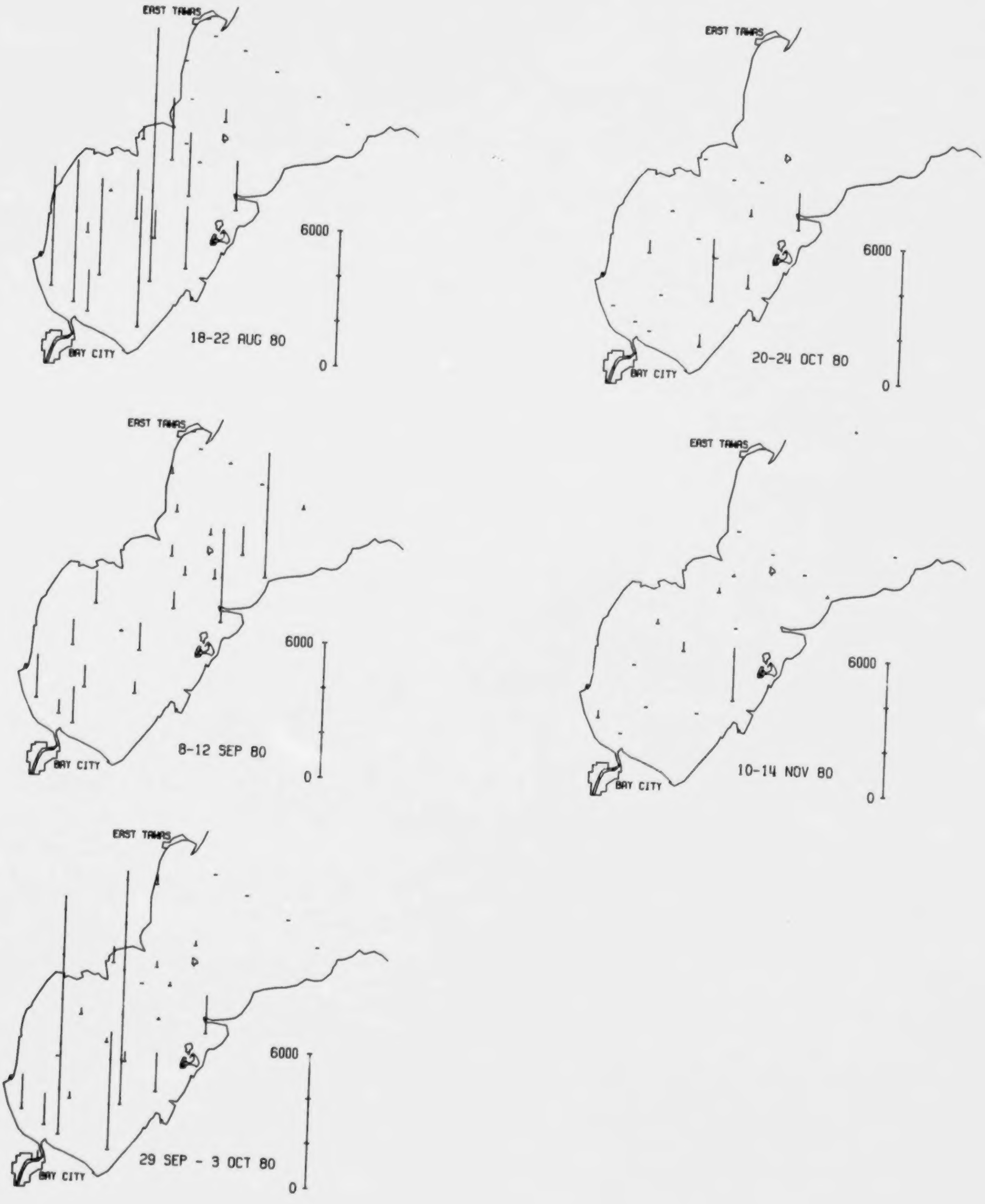

EAST TAWAS
BAY CITY
6000
0
18-22 AUG 80
20-24 OCT 80
8-12 SEP 80
10-14 NOV 80
29 SEP - 3 OCT 80

Figure 12. (continued).

areas. It reaches its maximum abundance in Saginaw Bay at stations near the river and along the eastern shore all the way to the mouth of the Bay. Its maximum distribution occurs in August and September when it is present in abundance at nearly all stations in the middle and inner Bay.

Anacystis incerta (Figure 13)

Unlike *A. cyanea*, this species is not particularly uncommon in the offshore waters of the Great Lakes, although it is generally most abundant in areas which have been significantly disturbed. In Lake Huron it occurs well into the fall and reaches its maximum in October later than most blue-green species (Kreis and Stoermer 1980). A similar pattern of seasonal occurrence has been noted in Lake Ontario (Stoermer *et al*. 1974). In Saginaw Bay, this species shows a clear preference for the eastern half of the Bay from July through September, reaching its maximum abundance in that region in August and September. However, moderate populations occur at the Bay-Lake Huron interface in September and October. Although abundance levels across the Bay decline somewhat after early October, significant cell densities persist through November.

Aphanizomenon gracile (Figure 14)

This species is a common important contributor to nuisance algal blooms in some eutrophic lakes. In Saginaw Bay its distribution is limited to Wild Fowl Bay and other nearshore eastern inner Bay stations. The first significant occurrence is in Wild Fowl Bay in late July. Large populations develop quickly at nearshore stations from Oak Point to the Quaniccassee River and low to moderate densities persist through November at these locations.

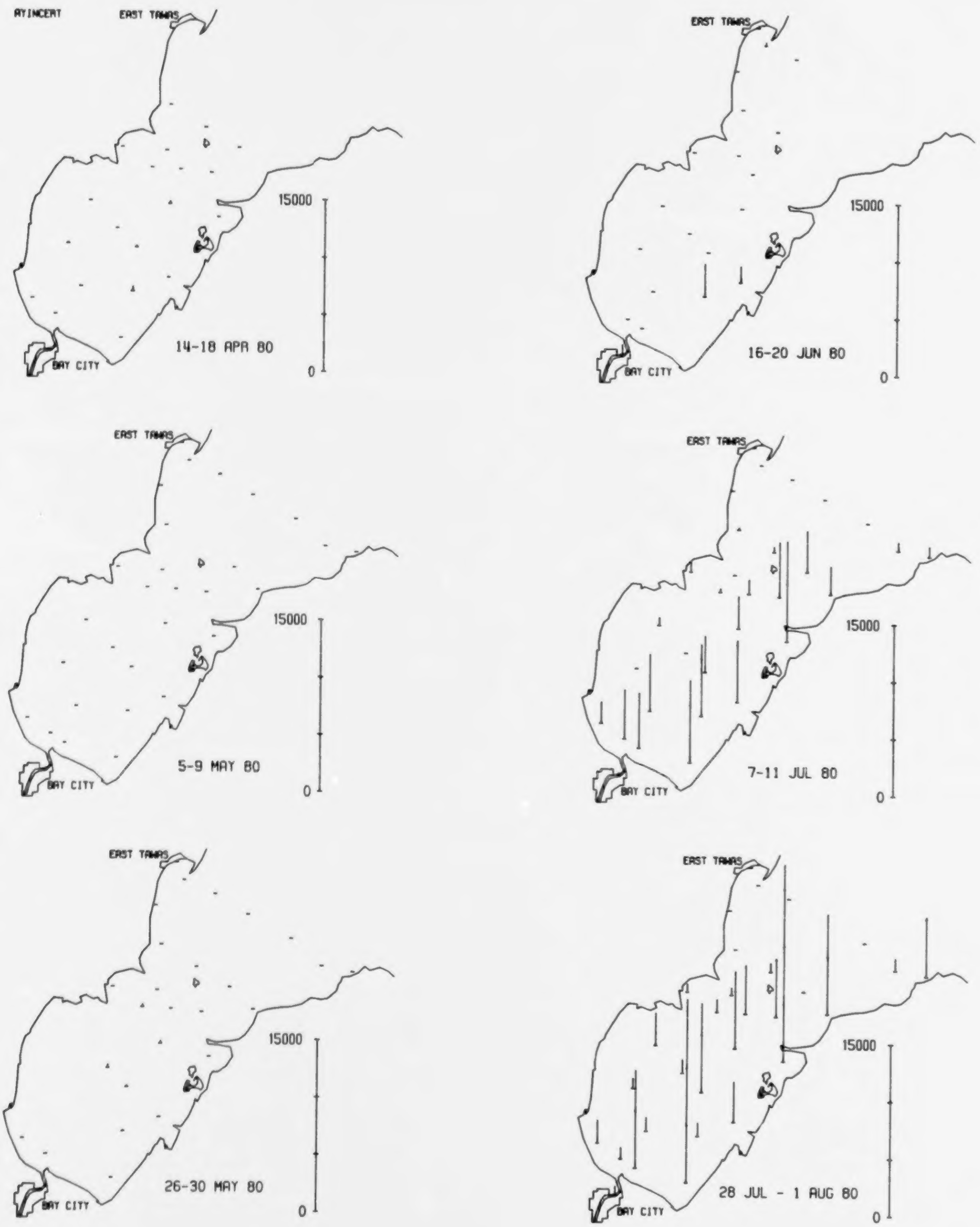

AYINCERT
EAST TAWAS
15000
0
14-18 APR 80
BAY CITY
16-20 JUN 80
5-9 MAY 80
7-11 JUL 80
26-30 MAY 80
28 JUL - 1 AUG 80

Figure 13. Distribution of *Anacystis incerta*.

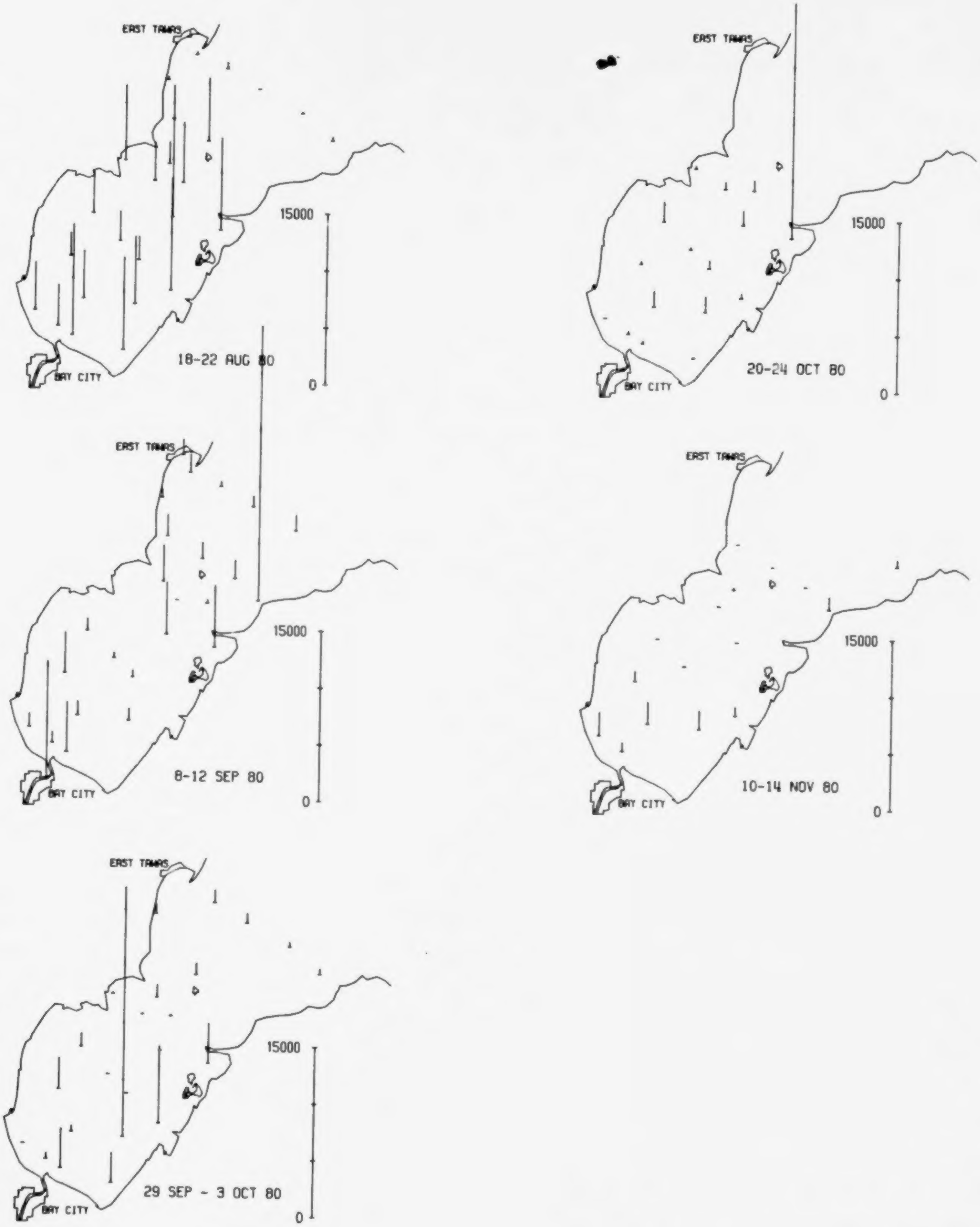

EAST TAWAS
BAY CITY
15000
0
18-22 AUG 80
20-24 OCT 80
8-12 SEP 80
10-14 NOV 80
29 SEP - 3 OCT 80

Figure 13. (continued).

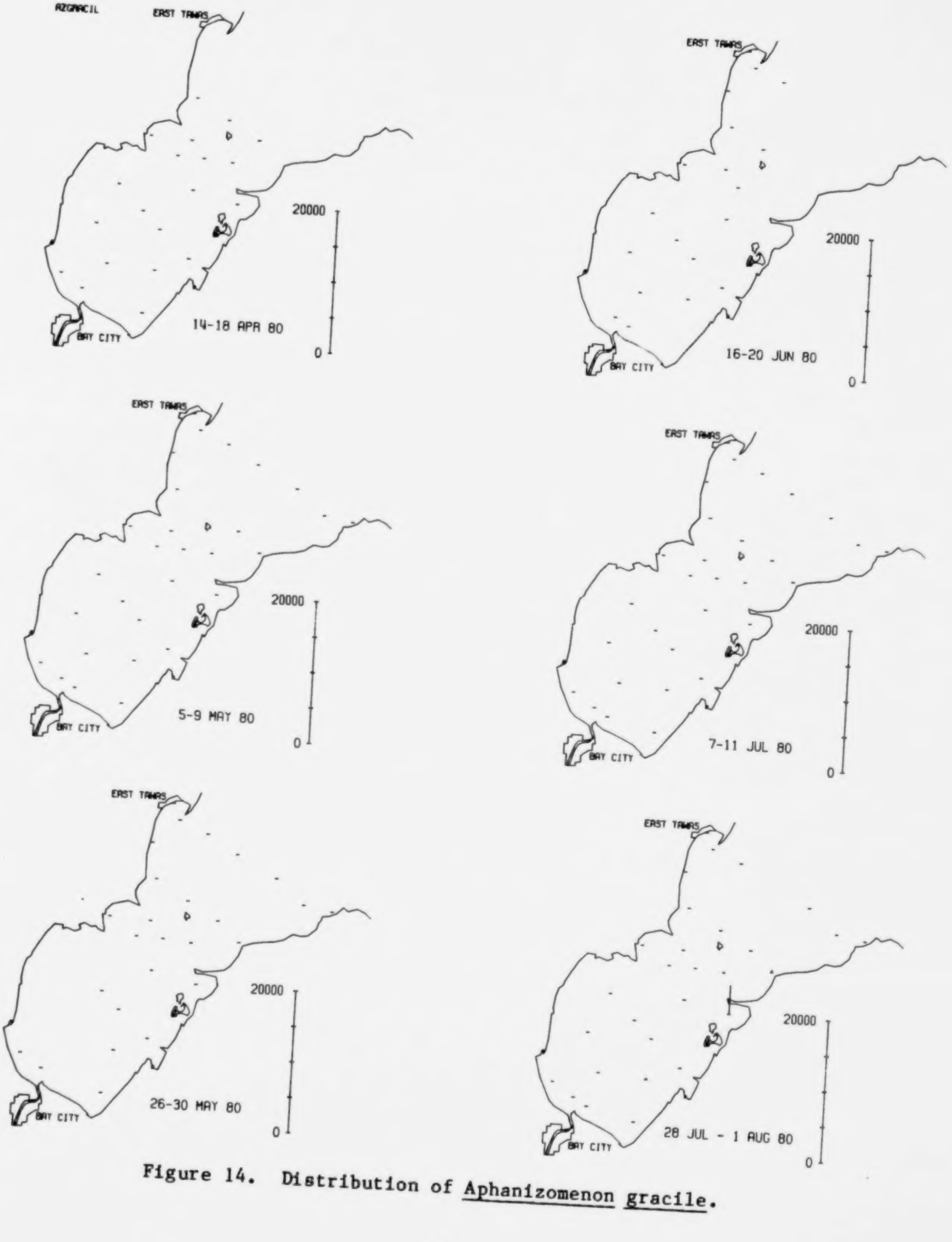

AZGRACIL
EAST TAWAS
20000
0
BAY CITY
14-18 APR 80
EAST TAWAS
20000
0
BAY CITY
16-20 JUN 80
EAST TAWAS
20000
0
BAY CITY
5-9 MAY 80
EAST TAWAS
20000
0
BAY CITY
7-11 JUL 80
EAST TAWAS
20000
0
BAY CITY
26-30 MAY 80
EAST TAWAS
20000
0
BAY CITY
28 JUL - 1 AUG 80

Figure 14. Distribution of Aphanizomenon gracile.

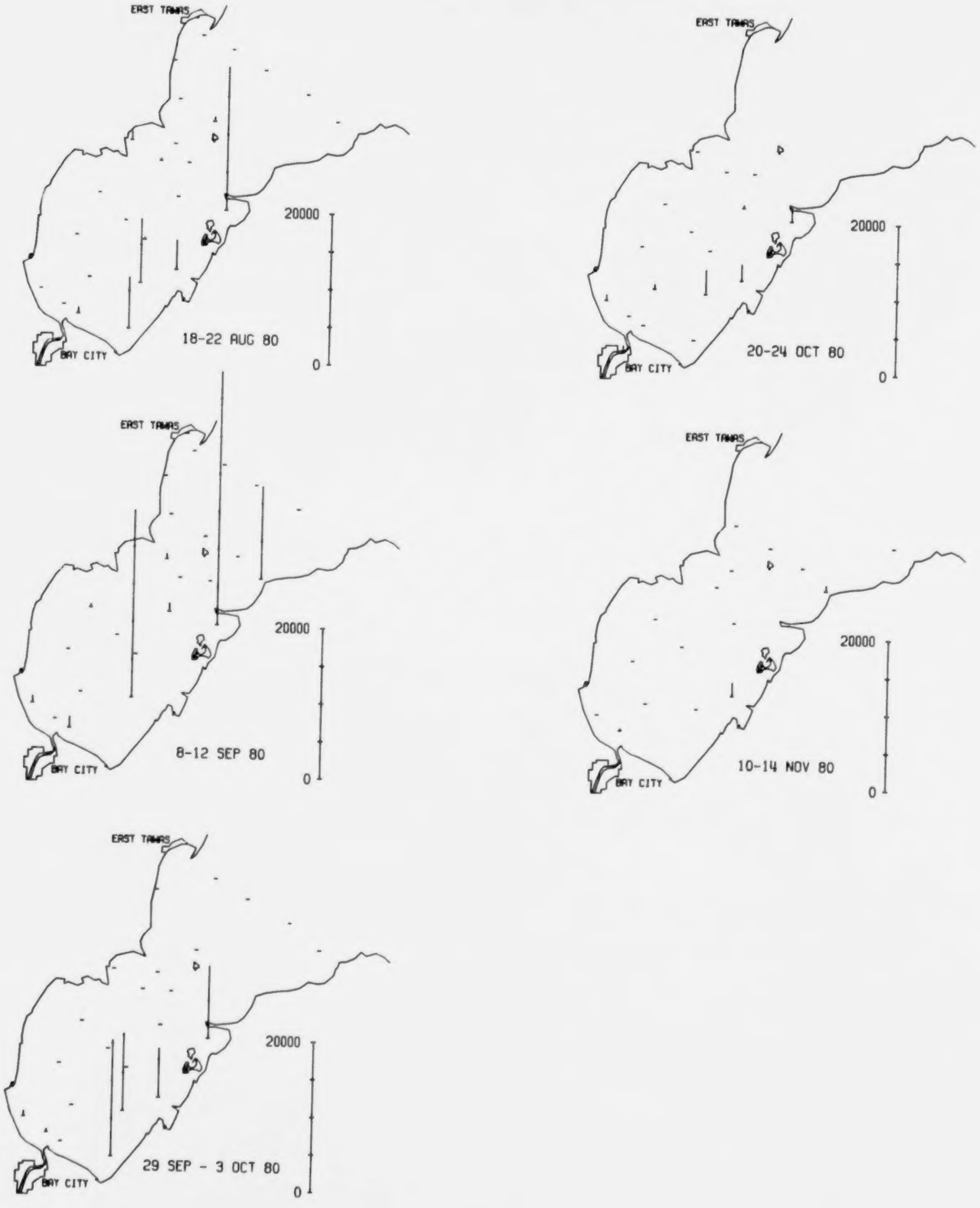

EAST TAWAS
BAY CITY
20000
0
18-22 AUG 80
EAST TAWAS
BAY CITY
20000
0
20-24 OCT 80
EAST TAWAS
BAY CITY
20000
0
8-12 SEP 80
EAST TAWAS
BAY CITY
20000
0
10-14 NOV 80
EAST TAWAS
BAY CITY
20000
0
29 SEP - 3 OCT 80

Figure 14. (continued).

This population seems to have completely replaced *A. flos-aquae*, which was previously abundant in many areas of Saginaw Bay (Stoermer *et al.* in publication). The main differentiating characteristics between the two species are in cell size (Huber-Pestalozzi 1938) and it is possible that the two entities represent different growth forms of the same species. This possibility has been debated in the literature without satisfactory resolution. Most authors have chosen to retain the distinction since it may be of ecological interest.

Gomphosphaeria lacustris (Figure 15)

This species is common in phytoplankton assemblages in mesotrophic to eutrophic lakes in the summer. However, in Saginaw Bay, detectable cell densities are already present in April at Wild Fowl Bay and nearby stations. Population levels build slowly and erratically through early July, stabilizing in late July, and then declining in late August. Moderate levels continue through November at inner and middle Bay stations. Maximum cell densities occur at nearshore stations near the river and along the eastern shore and to the Lake Huron interface. An exception occurs in August when a pulse was detected at stations from Point Au Gres eastward to Charity Island.

Microcoleus vaginatus (Figure 16)

This taxon reached its maximum abundance at nearshore stations in the outer and middle Bay and so is somewhat atypical compared to other blue-green algae. The only significant inner bay populations developed near the Saginaw and Quaniccassee Rivers and at Wild Fowl Bay.

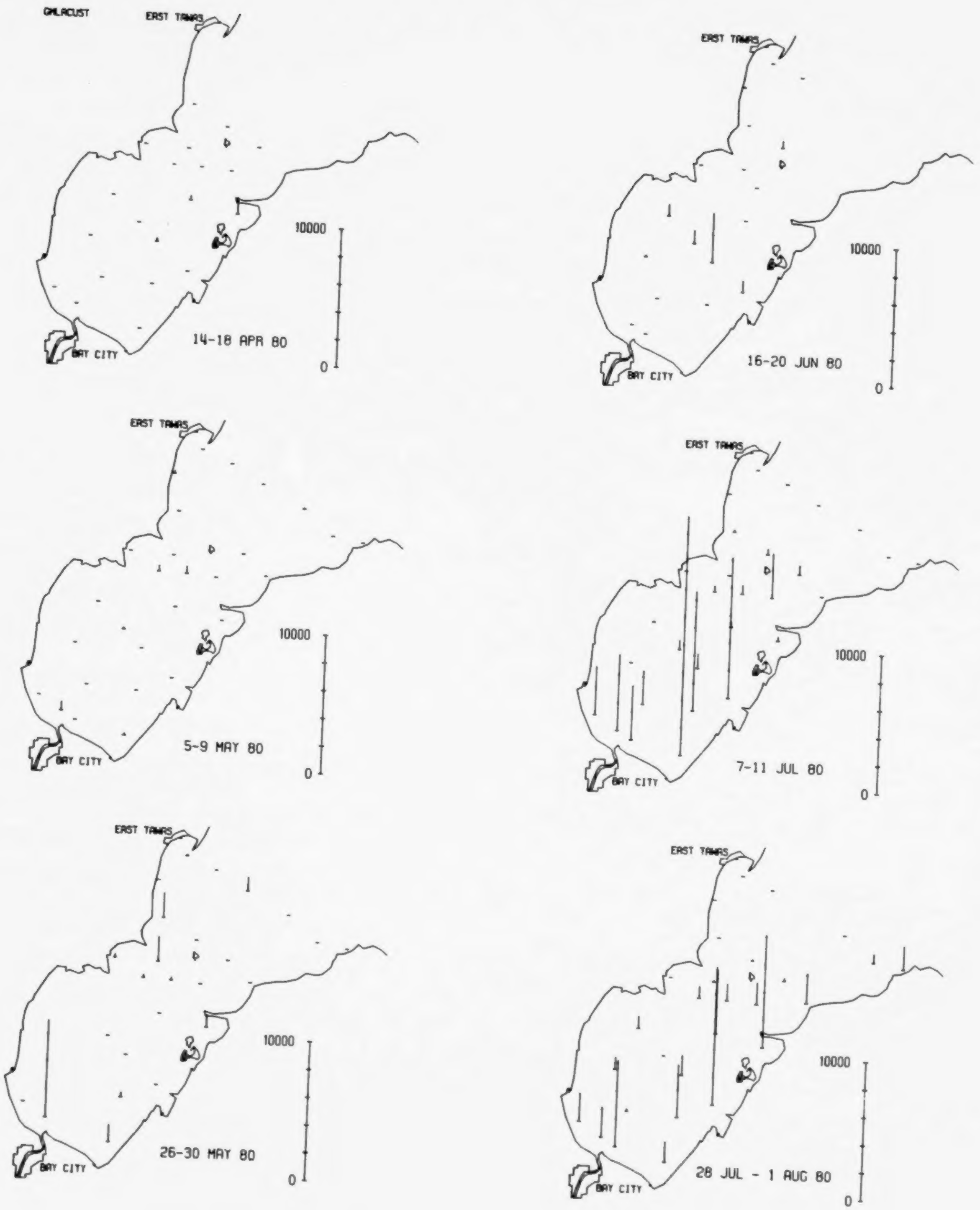
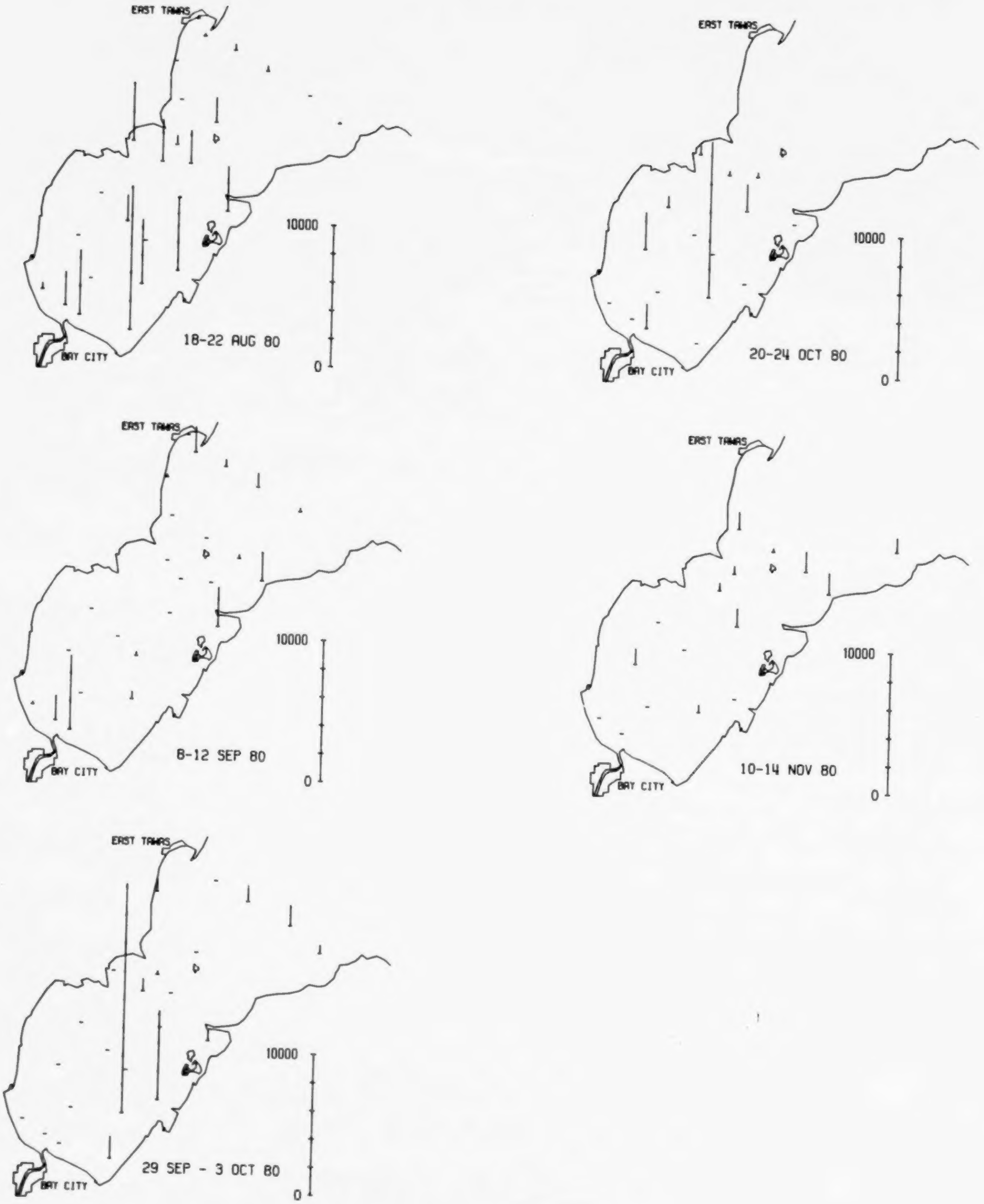

GMLACUST
EAST TAWAS
BAY CITY
14-18 APR 80
10000
0
EAST TAWAS
BAY CITY
16-20 JUN 80
10000
0
EAST TAWAS
BAY CITY
5-9 MAY 80
10000
0
EAST TAWAS
BAY CITY
7-11 JUL 80
10000
0
EAST TAWAS
BAY CITY
26-30 MAY 80
10000
0
EAST TAWAS
BAY CITY
28 JUL - 1 AUG 80
10000
0

Figure 15. Distribution of Gomphosphaeria lacustris.


EAST TAWAS
BAY CITY
10000
0

18-22 AUG 80

20-24 OCT 80

8-12 SEP 80

10-14 NOV 80

29 SEP - 3 OCT 80

Figure 15. (continued).

in late July, and then declining in late August. Moderate levels continue through November at inner and middle Bay stations. Maximum cell densities occur at nearshore stations near the river and along the eastern shore and to the Lake Huron interface. An exception occurs in August when a pulse was detected at stations from Point Au Gres eastward to Charity Island.

Microcoleus vaginatus (Figure 16)

This taxon reached its maximum abundance at nearshore stations in the outer and middle Bay and so is somewhat atypical compared to other blue-green algae. The only significant inner bay populations developed near the Saginaw and Quaniccassee Rivers and at Wild Fowl Bay.

Oscillatoria limnetica (Figure 17)

This blue-green filament is rarely reported from the Great Lakes. In Lake Ontario, it was the most abundant alga on an annual basis in terms of cell densities and the most important blue-green in terms of estimated cell carbon content (Stoermer and Ladewski 1978). In Lake Huron, it occurred only sporadically and was never very abundant (Stoermer and Kreis 1980). In Saginaw Bay, it is mainly restricted to the Saginaw River and Wild Fowl Bay. Lower densities also occurred at Oak Point and at stations near the Quaniccassee River. Maximum cell densities occurred in August and populations persisted through September.

Oscillatoria retzii (Figure 18)

This species is rarely recorded from the upper Great Lakes, but is abundant in eutrophic environments. In Saginaw Bay, it first appeared in late

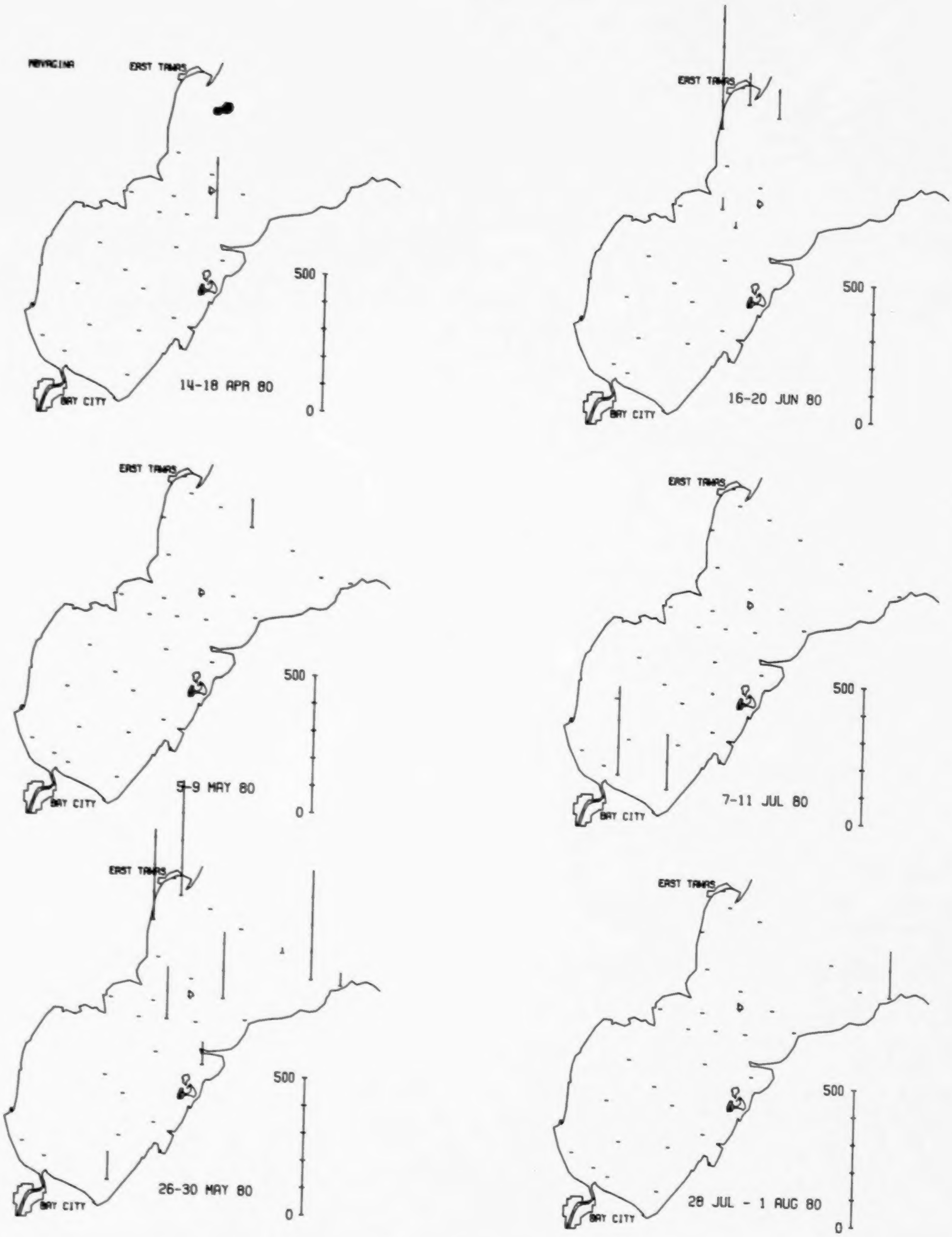

MCVAGINA
EAST TAWAS
500
0
14-18 APR 80
BAY CITY
EAST TAWAS
500
0
16-20 JUN 80
BAY CITY
EAST TAWAS
500
0
5-9 MAY 80
BAY CITY
EAST TAWAS
500
0
7-11 JUL 80
BAY CITY
EAST TAWAS
500
0
26-30 MAY 80
BAY CITY
EAST TAWAS
500
0
28 JUL - 1 AUG 80
BAY CITY

Figure 16. Distribution of Microcoleus vaginatus.

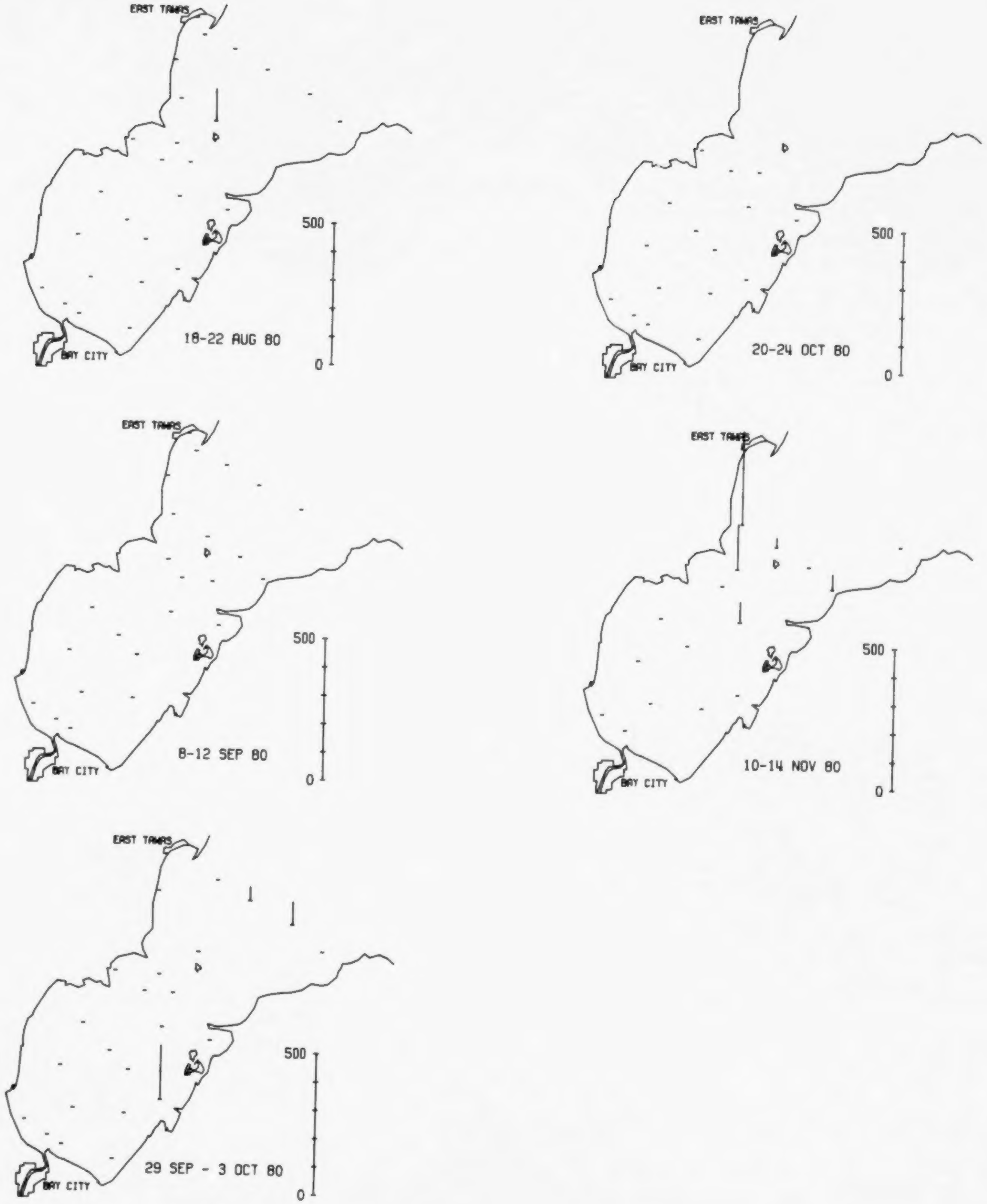

EAST TAWAS
500
0
BAY CITY
18-22 AUG 80
EAST TAWAS
500
0
BAY CITY
20-24 OCT 80
EAST TAWAS
500
0
BAY CITY
8-12 SEP 80
EAST TAWAS
500
0
BAY CITY
10-14 NOV 80
EAST TAWAS
500
0
BAY CITY
29 SEP - 3 OCT 80

Figure 16. (continued).

Oscillatoria limnetica (Figure 17)

This blue-green filament is rarely reported from the Great Lakes. In Lake Ontario, it was the most abundant alga on an annual basis in terms of cell densities and the most important blue-green in terms of estimated cell carbon content (Stoermer and Ladewski 1978). In Lake Huron, it occurred only sporadically and was never very abundant (Stoermer and Kreis 1980). In Saginaw Bay, it is mainly restricted to the Saginaw River and Wild Fowl Bay. Lower densities also occurred at Oak Point and at stations near the Quaniccassee River. Maximum cell densities occurred in August and populations persisted through September.

Oscillatoria retzii (Figure 18)

This species is rarely recorded from the upper Great Lakes, but is abundant in eutrophic environments. In Saginaw Bay, it first appeared in late May samples and exhibited a short pulse in June in the Saginaw River. It persisted through October in stations near the river mouth. Its broadest areal distribution coincided with a second bloom in September and early October. Except for sporadic occurrences near Charity Island, Oak Point, and Wild Fowl Bay, it was found mainly in the inner Bay.

Pelonema spp. (Figure 19)

This atypical and apparently achlorotic filamentous species is rarely reported in the literature. It seems closely related to the group of heterotrophic, filamentous species which have classically been treated in both the phycological and bacteriological literature. Unlike most of these species, it often occurs in highly oxygenated waters and has been noted in the plankton of

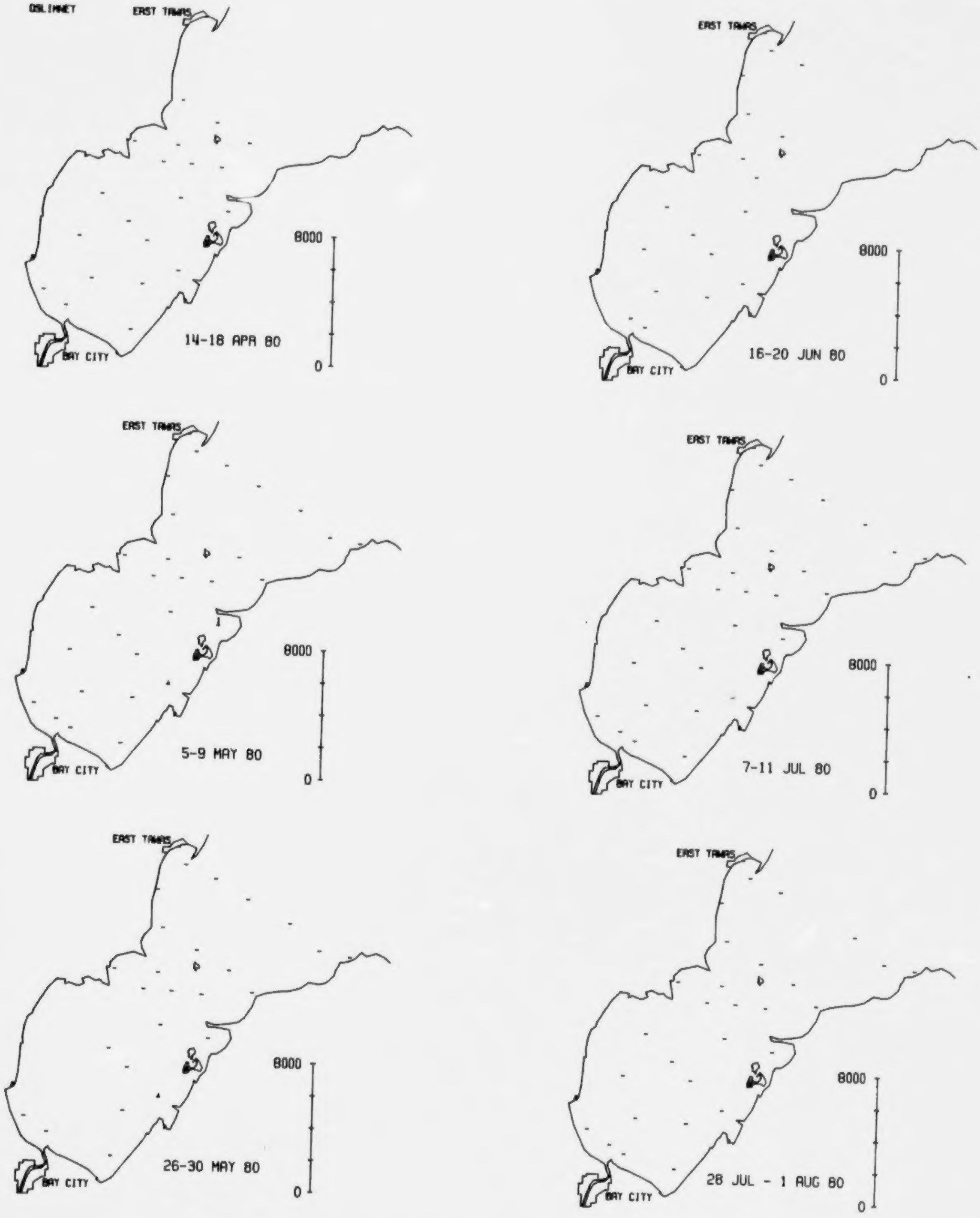

OSLIMNET
EAST TAWAS
BAY CITY
8000
0
14-18 APR 80
EAST TAWAS
BAY CITY
8000
0
16-20 JUN 80
EAST TAWAS
BAY CITY
8000
0
5-9 MAY 80
EAST TAWAS
BAY CITY
8000
0
7-11 JUL 80
EAST TAWAS
BAY CITY
8000
0
26-30 MAY 80
EAST TAWAS
BAY CITY
8000
0
28 JUL - 1 AUG 80

Figure 17. Distribution of Oscillatoria limnetica.

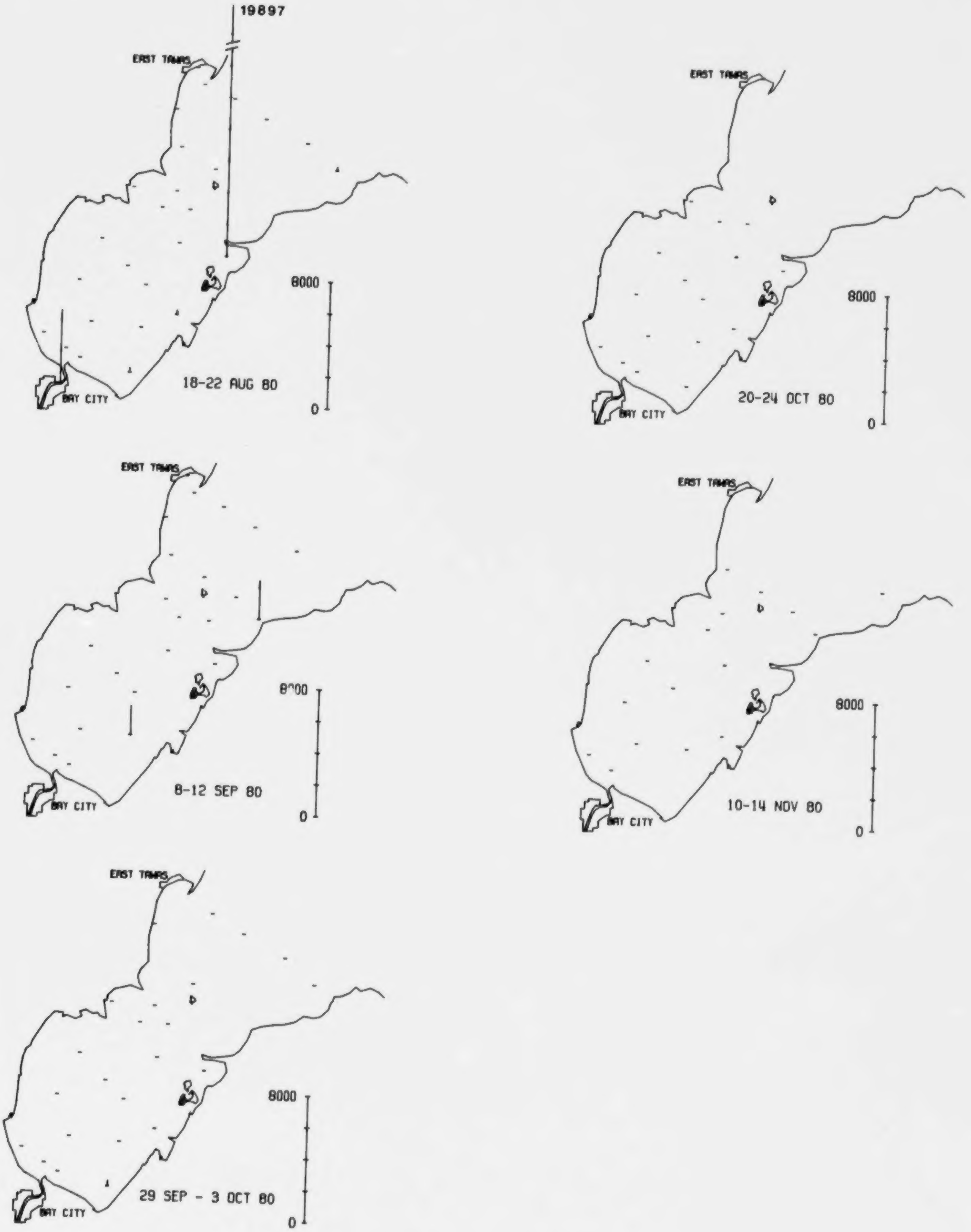

19897
EAST TAWAS
BAY CITY
8000
0
18-22 AUG 80
EAST TAWAS
BAY CITY
8000
0
20-24 OCT 80
EAST TAWAS
BAY CITY
8000
0
8-12 SEP 80
EAST TAWAS
BAY CITY
8000
0
10-14 NOV 80
EAST TAWAS
BAY CITY
8000
0
29 SEP - 3 OCT 80

Figure 17. (continued).

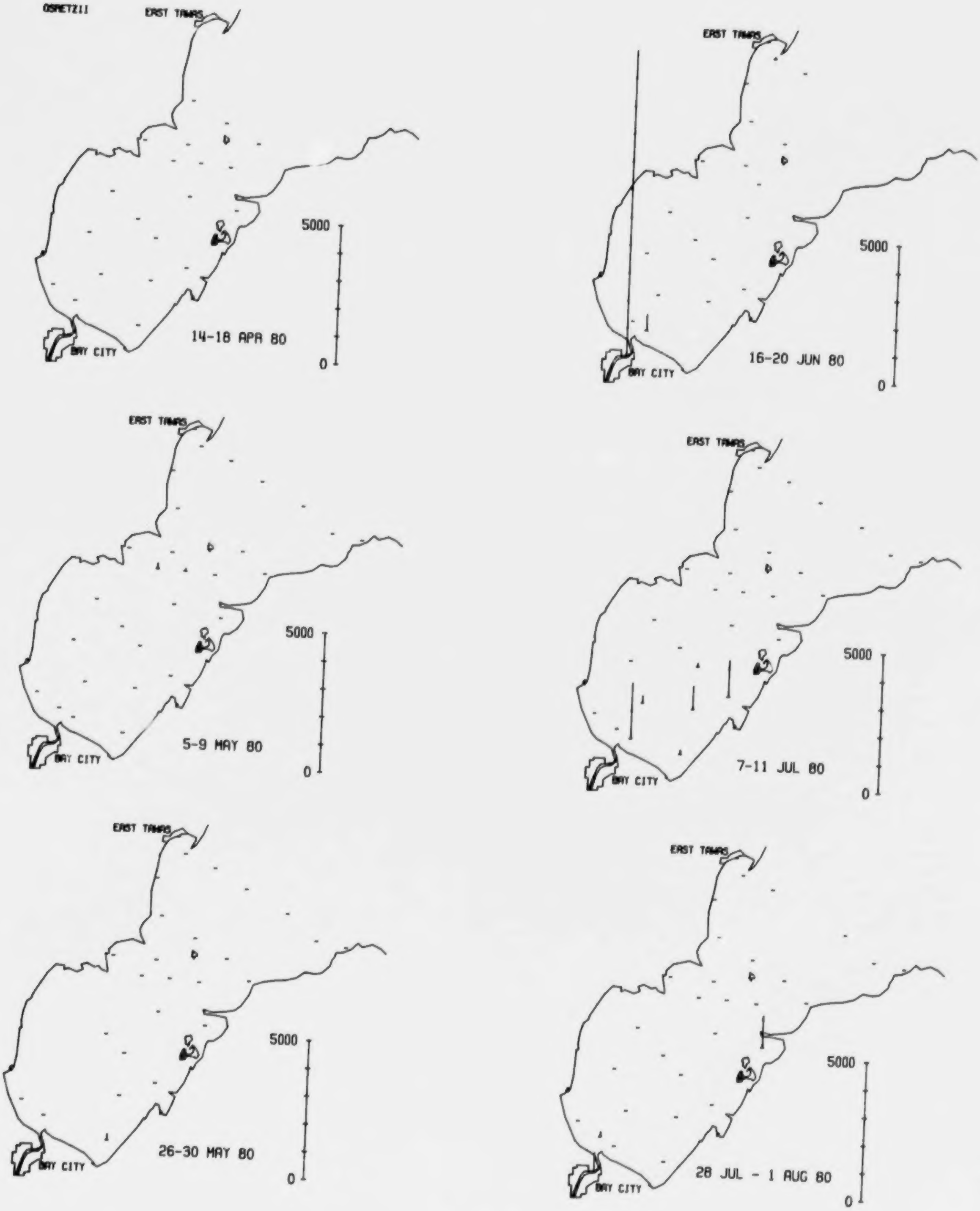

OSRETZII
EAST TAWAS
BAY CITY
14-18 APR 80
5000
0
EAST TAWAS
BAY CITY
16-20 JUN 80
5000
0
EAST TAWAS
BAY CITY
5-9 MAY 80
5000
0
EAST TAWAS
BAY CITY
7-11 JUL 80
5000
0
EAST TAWAS
BAY CITY
26-30 MAY 80
5000
0
EAST TAWAS
BAY CITY
28 JUL - 1 AUG 80
5000
0

Figure 18. Distribution of *Oscillatoria retzii*.

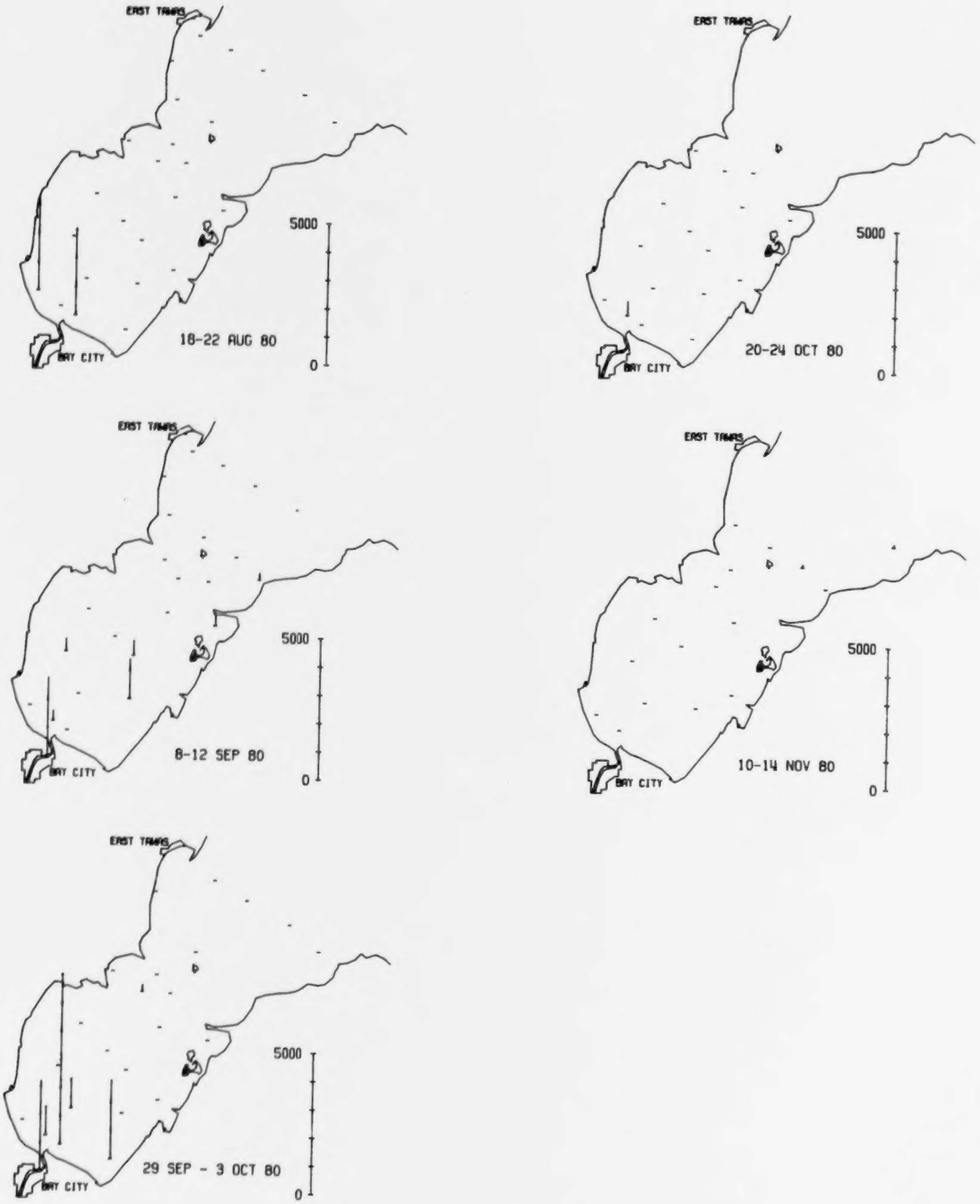

EAST TAWAS
5000
0
18-22 AUG 80
BAY CITY
EAST TAWAS
5000
0
20-24 OCT 80
BAY CITY
EAST TAWAS
5000
0
8-12 SEP 80
BAY CITY
EAST TAWAS
5000
0
10-14 NOV 80
BAY CITY
EAST TAWAS
5000
0
29 SEP - 3 OCT 80
BAY CITY

Figure 18. (continued).

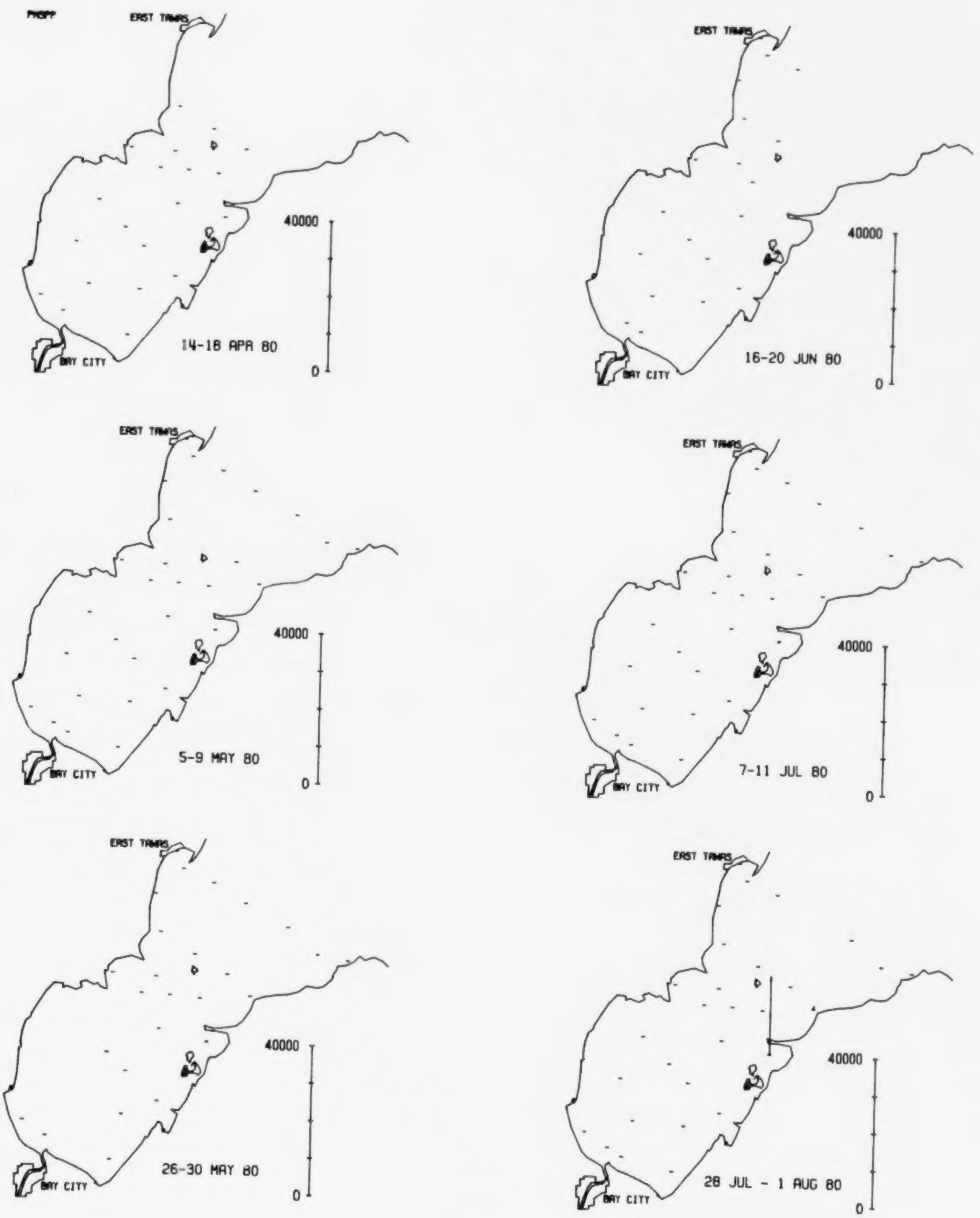

PNSPP
EAST TAWAS
BAY CITY
14-18 APR 80
40000
0
EAST TAWAS
BAY CITY
16-20 JUN 80
40000
0
EAST TAWAS
BAY CITY
5-9 MAY 80
40000
0
EAST TAWAS
BAY CITY
7-11 JUL 80
40000
0
EAST TAWAS
BAY CITY
26-30 MAY 80
40000
0
EAST TAWAS
BAY CITY
28 JUL - 1 AUG 80
40000
0

Figure 19. Distribution of Pelonema sp.

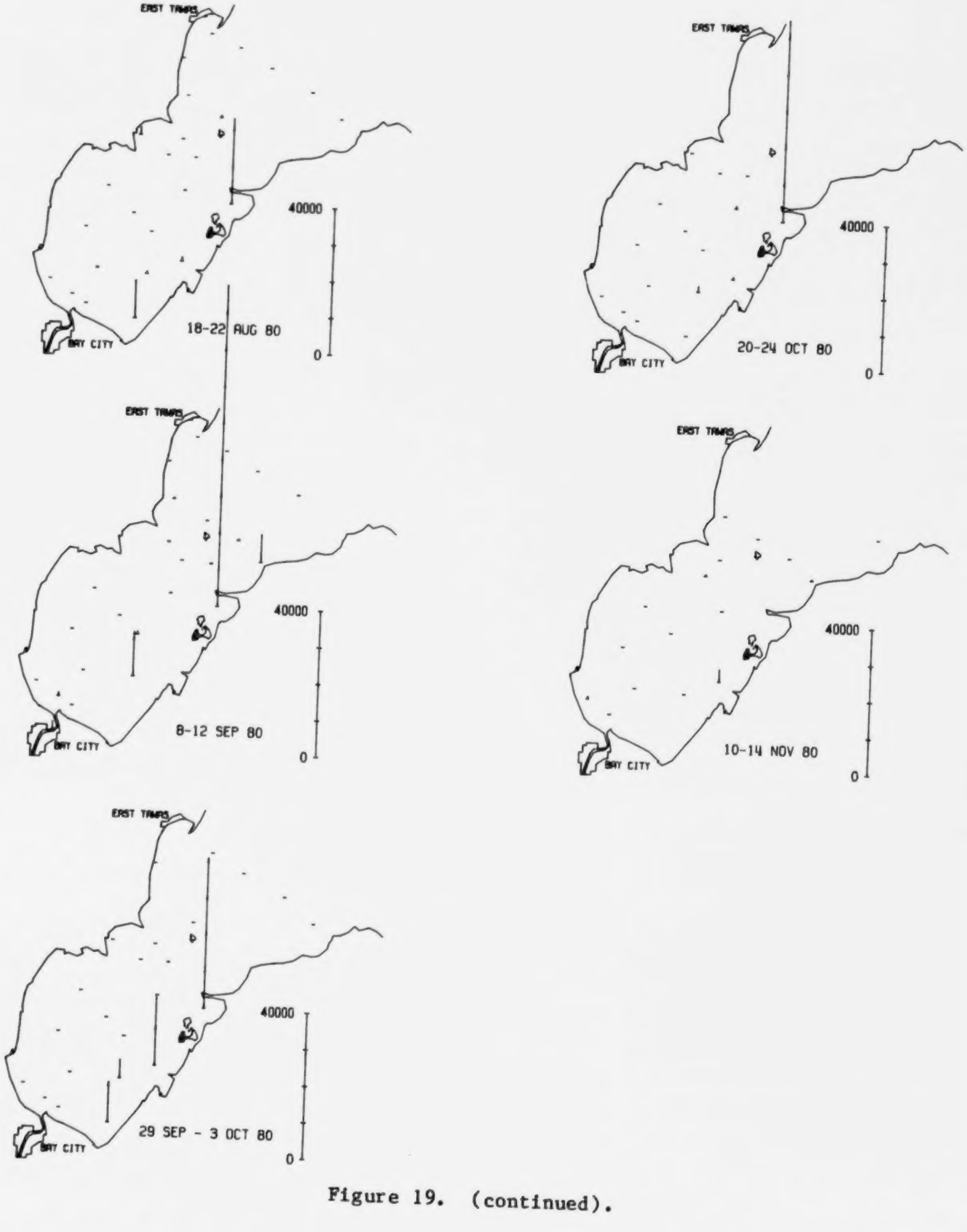

EAST TAWAS
BAY CITY
40000
0
18-22 AUG 80
EAST TAWAS
BAY CITY
40000
0
20-24 OCT 80
EAST TAWAS
BAY CITY
40000
0
8-12 SEP 80
EAST TAWAS
BAY CITY
40000
0
10-14 NOV 80
EAST TAWAS
BAY CITY
40000
0
29 SEP - 3 OCT 80

Figure 19. (continued).

disturbed, originally oligotrophic, alpine lakes in Europe (Huber-Pestalozzi 1938). In Saginaw Bay it is a numerically import component of phytoplankton assemblages at a limited number of stations in the nearshore area from the Quaniccassee River area to Oak Point. It is one of the dominants at Wild Fowl Bay where it reaches its maximum cell densities. The high level of abundance of Pelonema in this area is possibly indicative of organic loadings, although further investigation would be necessary to establish this.

Porphyrosiphon sp. (Figure 20)

This genus is rarely reported from the Great Lakes. In Saginaw Bay it is one of the summer dominants, appearing first in June, reaching its maximum in early September, and then declining in October. It reaches its maximum densities at stations in and near the River, at Wild Fowl Bay and at mid-Bay stations in the shallow water around Charity Island.

Schizothrix calcicola (Figure 21)

One of the important taxonomic characteristics of this species is lack of definite cross walls betwween individual cells. Consequently, abundances reported here for this species are in filaments/ml rather than cells/ml and so cell densities are underestimated by a factor of 10-30 times. By either density estimate, it is one of the dominants at inner Bay stations from August through October. Before and after this period, its spatial distribution was sporadic and it occurred only occasionally in high abundance, especially at nearshore stations and at Wild Fowl Bay. Its greatest abundance at a single station was in late July-early August at Station 54 in the Saginaw River near the town of Bay City.

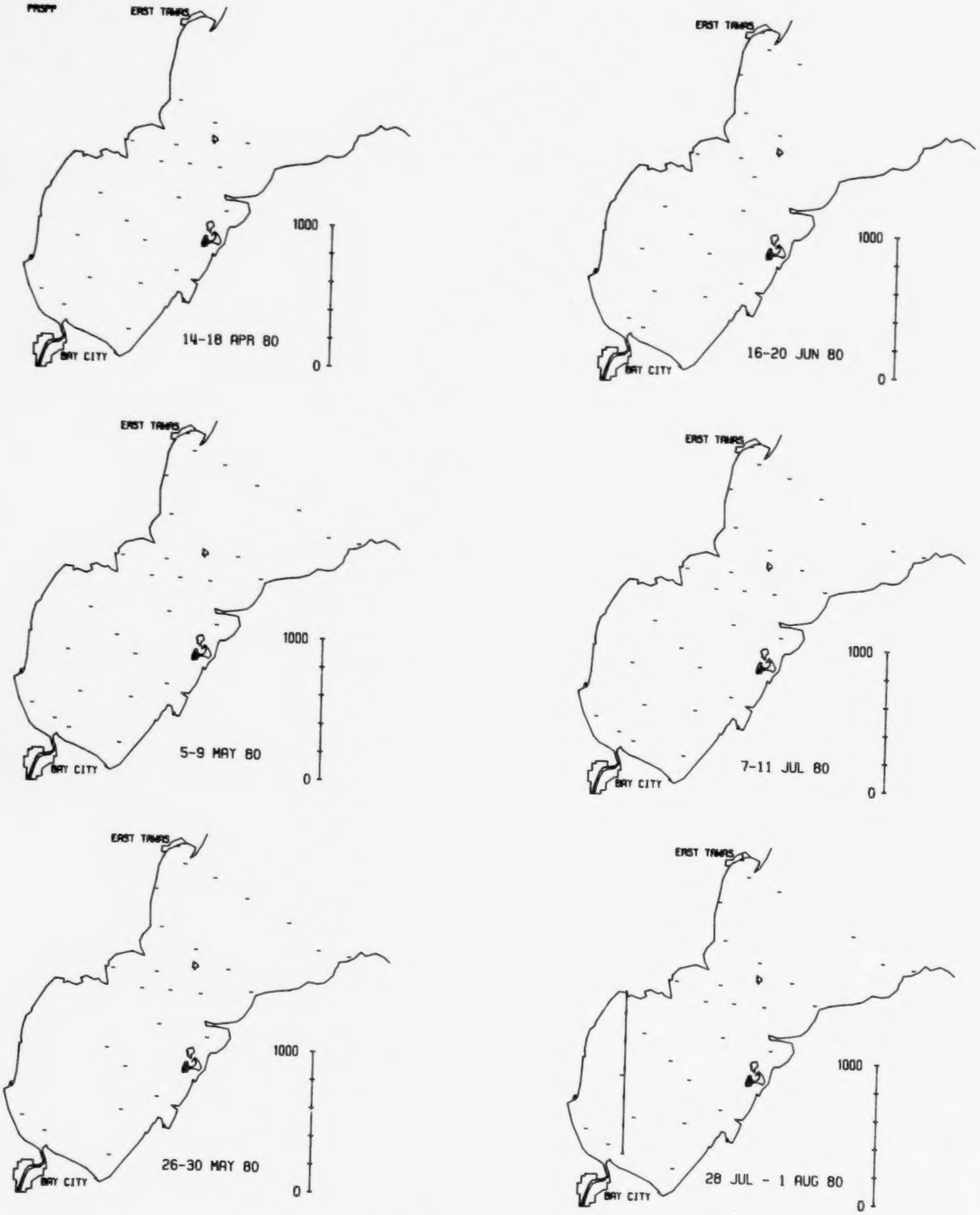

PRSPP
EAST TAWAS
BAY CITY
14-18 APR 80
1000
0
EAST TAWAS
BAY CITY
16-20 JUN 80
1000
0
EAST TAWAS
BAY CITY
5-9 MAY 80
1000
0
EAST TAWAS
BAY CITY
7-11 JUL 80
1000
0
EAST TAWAS
BAY CITY
26-30 MAY 80
1000
0
EAST TAWAS
BAY CITY
28 JUL - 1 AUG 80
1000
0

Figure 20. Distribution of Porphyrosiphon sp.

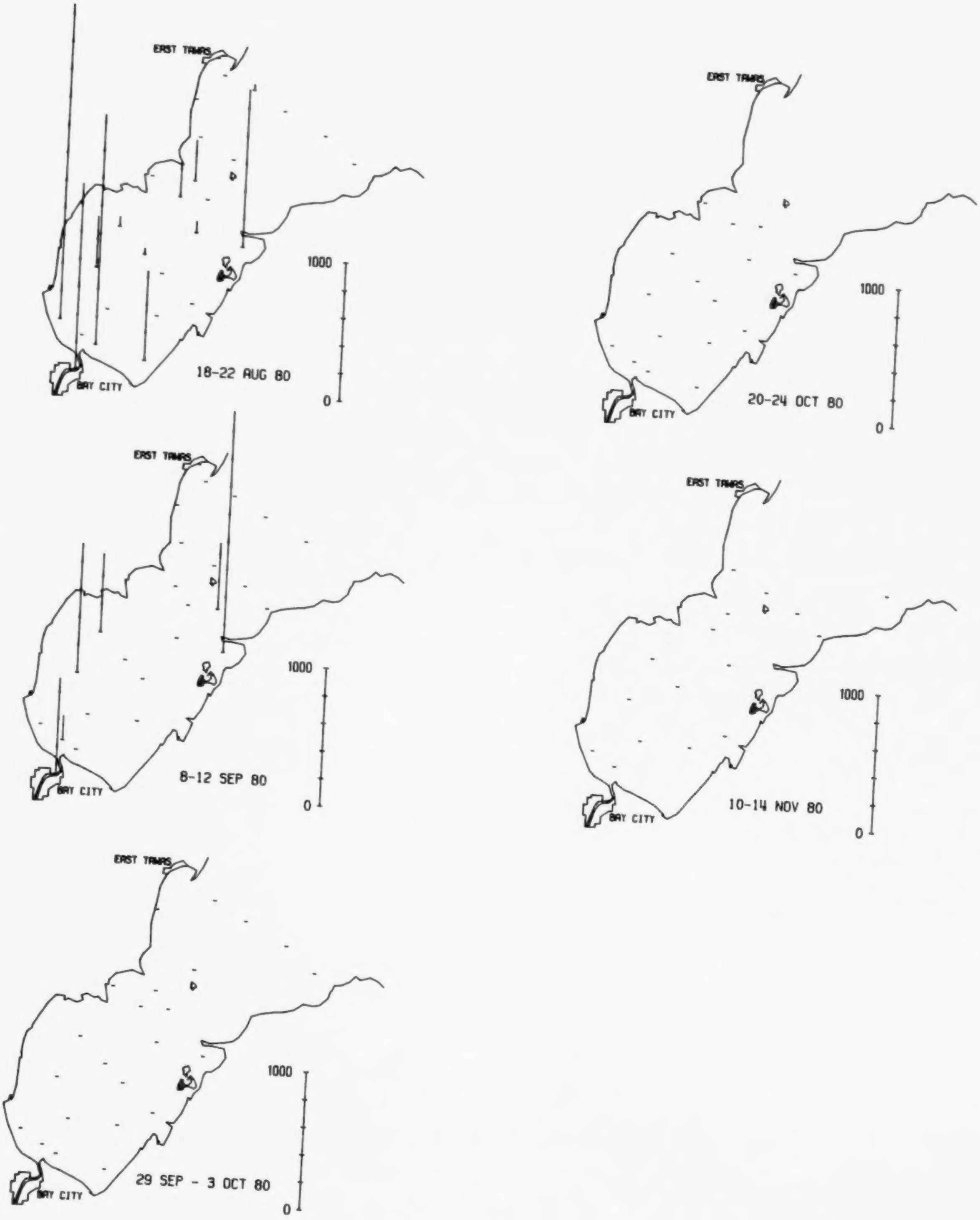

EAST TAWAS
BAY CITY
18-22 AUG 80
1000
0
EAST TAWAS
BAY CITY
20-24 OCT 80
1000
0
EAST TAWAS
BAY CITY
8-12 SEP 80
1000
0
EAST TAWAS
BAY CITY
10-14 NOV 80
1000
0
EAST TAWAS
BAY CITY
29 SEP - 3 OCT 80
1000
0

Figure 20. (continued).

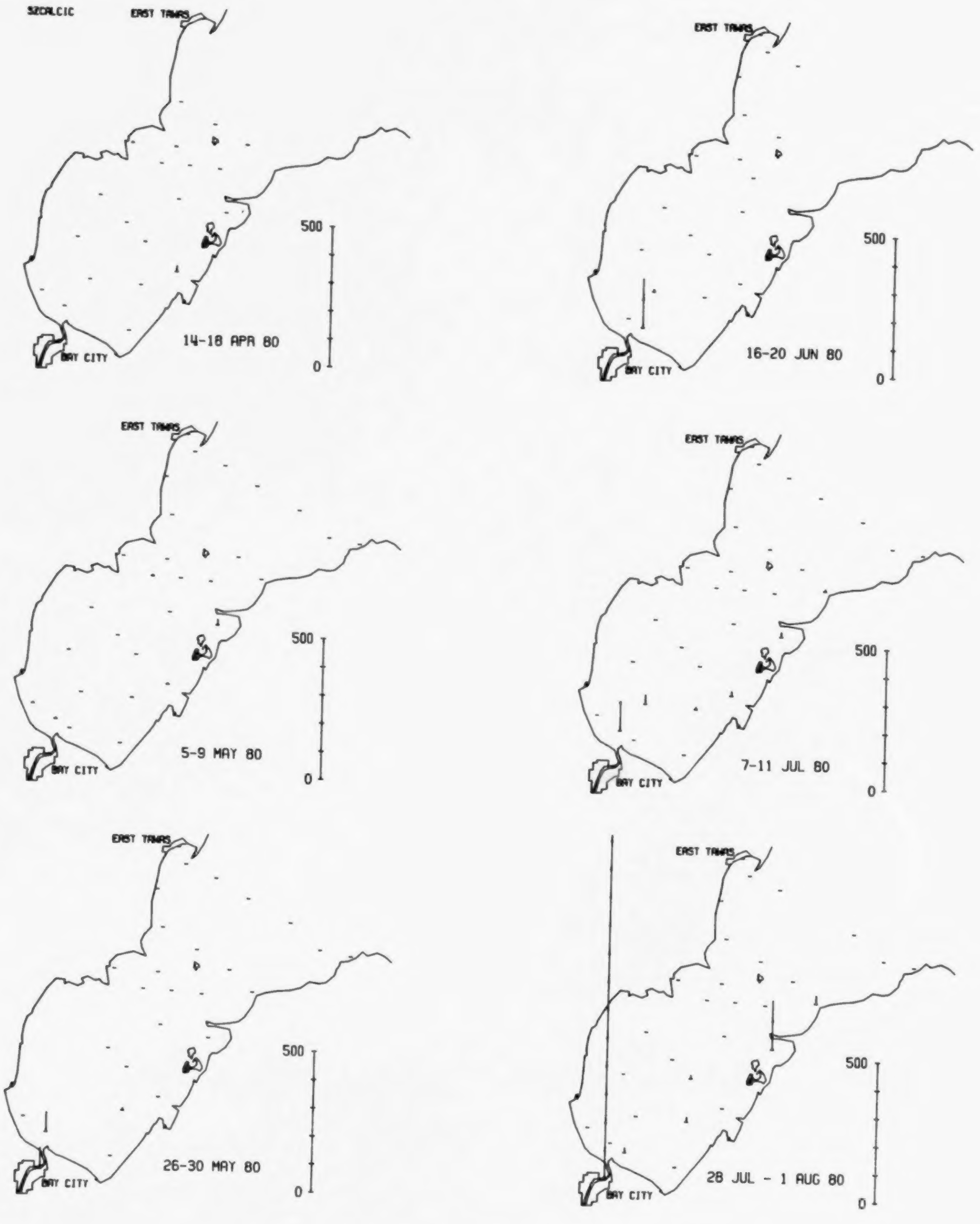

SZCALCIC
EAST TAWAS
BAY CITY
14-18 APR 80
500
0
16-20 JUN 80
5-9 MAY 80
7-11 JUL 80
26-30 MAY 80
28 JUL - 1 AUG 80

Figure 21. Distribution of Schizothrix calcicola.

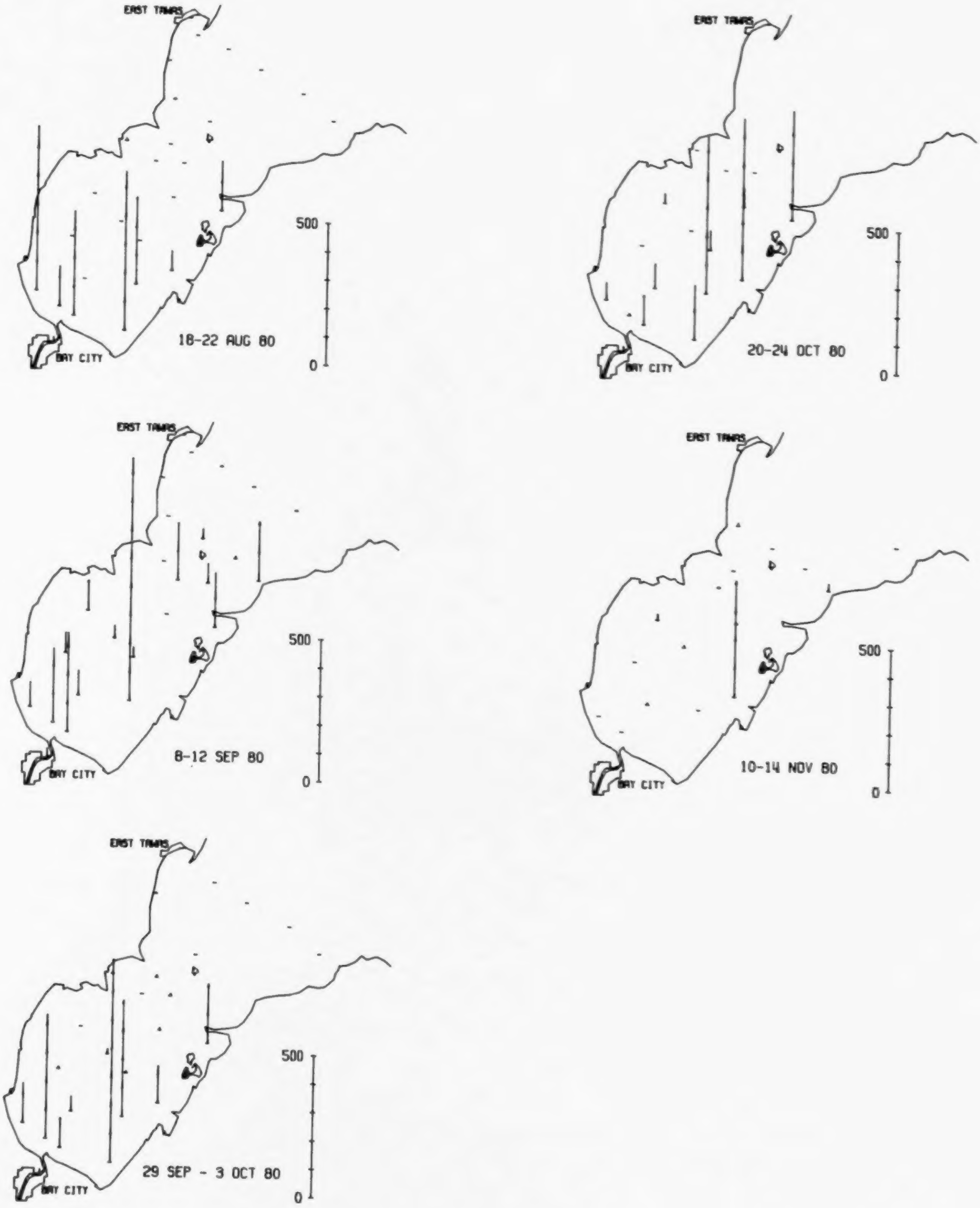

EAST TAWAS
BAY CITY
18-22 AUG 80
500
0
EAST TAWAS
BAY CITY
20-24 OCT 80
500
0
EAST TAWAS
BAY CITY
8-12 SEP 80
500
0
EAST TAWAS
BAY CITY
10-14 NOV 80
500
0
EAST TAWAS
BAY CITY
29 SEP - 3 OCT 80
500
0

Figure 21. (continued).

Bacillariophyta or Diatoms (Figure 22)

Members of this division are common and abundant in fresh, brackish, and marine environments. Although commonly associated with spring blooms in most lakes, diatoms reach their greatest absolute abundance in Saginaw Bay in September and October. However, diatoms are relatively abundant in spring and do show declines in absolute abundance at some stations in June and July. During early summer, maximum abundances occur at and near the river and in Wild Fowl Bay. During late summer and fall, inner Bay stations have much higher cell densities than Bay-Lake Huron interface stations.

Cyclotella comensis (Figure 23)

The seasonal and spatial distribution of this species in Saginaw Bay is somewhat unusual for a diatom. Through June, low cell densities occur in the outer and middle Bay. A strong pulse develops in July and August, highest densities occur in the middle Bay and in the nearshore areas of the outer Bay. In early August, moderate levels develop in the inner Bay and by late August, *C. comensis* is uniformly distributed across the inner and middle Bay. Cell densities in the inner Bay drop in September, while high abundances persist in the middle Bay. Abundances decline from late September through November. Stoermer and Kreis (1980) found high abundances of this species in late summer in Lake Huron. It had been found in the upper Great Lakes in low abundance (Schelske *et al*. 1972, 1974; Lowe 1976). Its distribution in Lake Huron and Saginaw Bay indicates that this species flourishes under low concentrations of silica and high concentrations of nitrate (Stoermer and Kreis 1980).

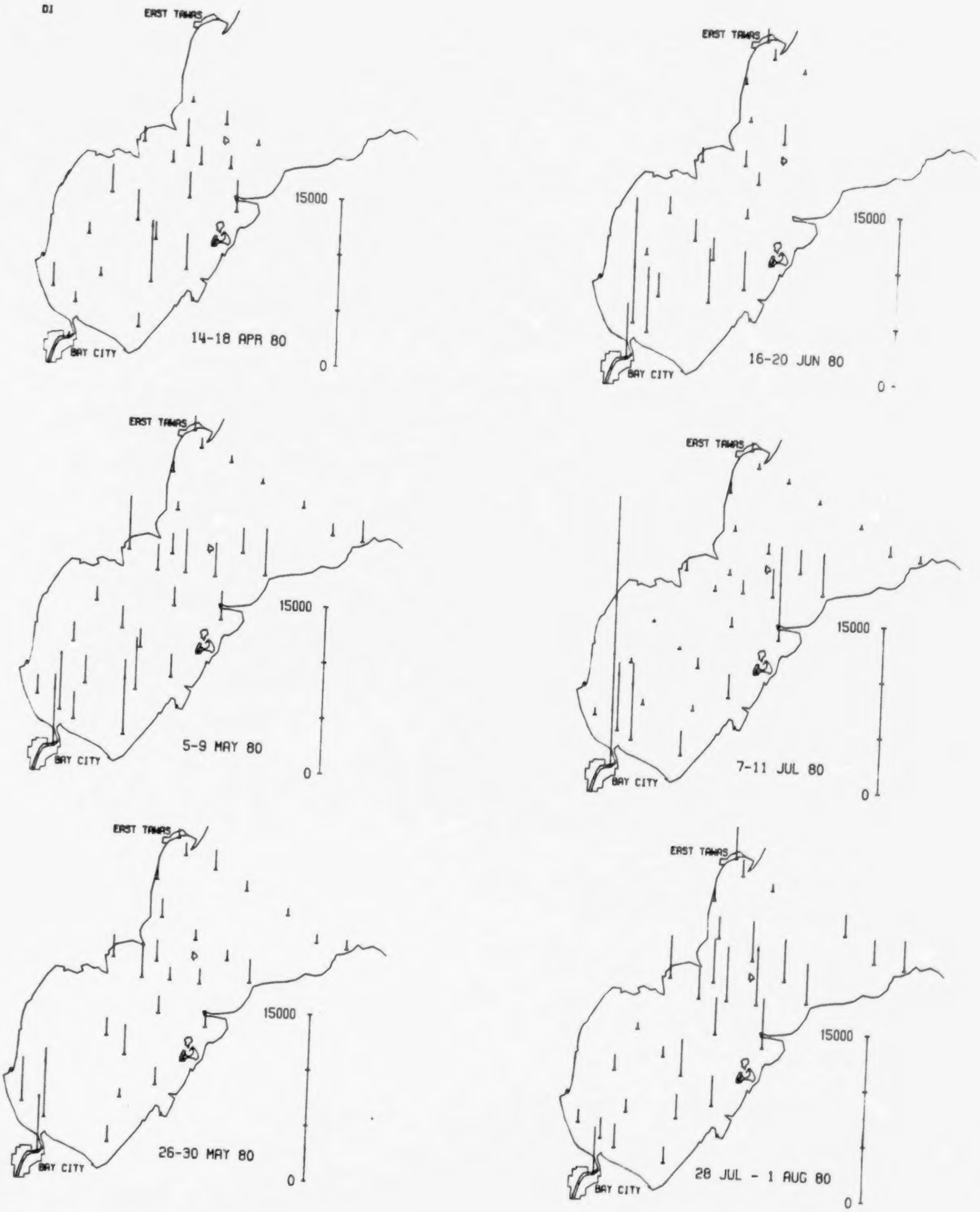

DI
EAST TAWAS
BAY CITY
15000
0
14-18 APR 80
16-20 JUN 80
5-9 MAY 80
7-11 JUL 80
26-30 MAY 80
28 JUL - 1 AUG 80

Figure 22. Distribution of diatoms.

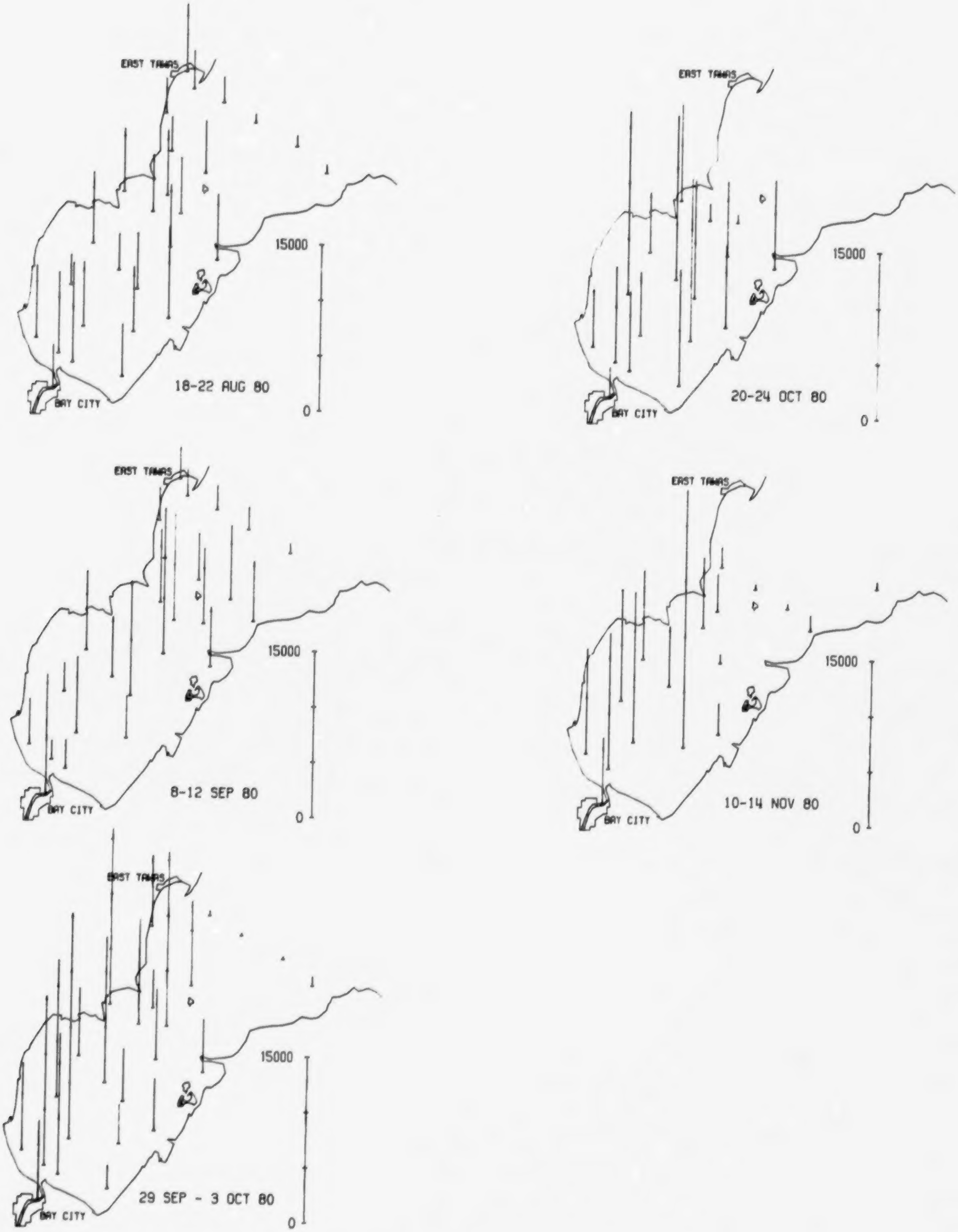

EAST TAWAS
15000
0
18-22 AUG 80
BAY CITY
EAST TAWAS
15000
0
20-24 OCT 80
BAY CITY
EAST TAWAS
15000
0
8-12 SEP 80
BAY CITY
EAST TAWAS
15000
0
10-14 NOV 80
BAY CITY
EAST TAWAS
15000
0
29 SEP - 3 OCT 80
BAY CITY

Figure 22. (continued).

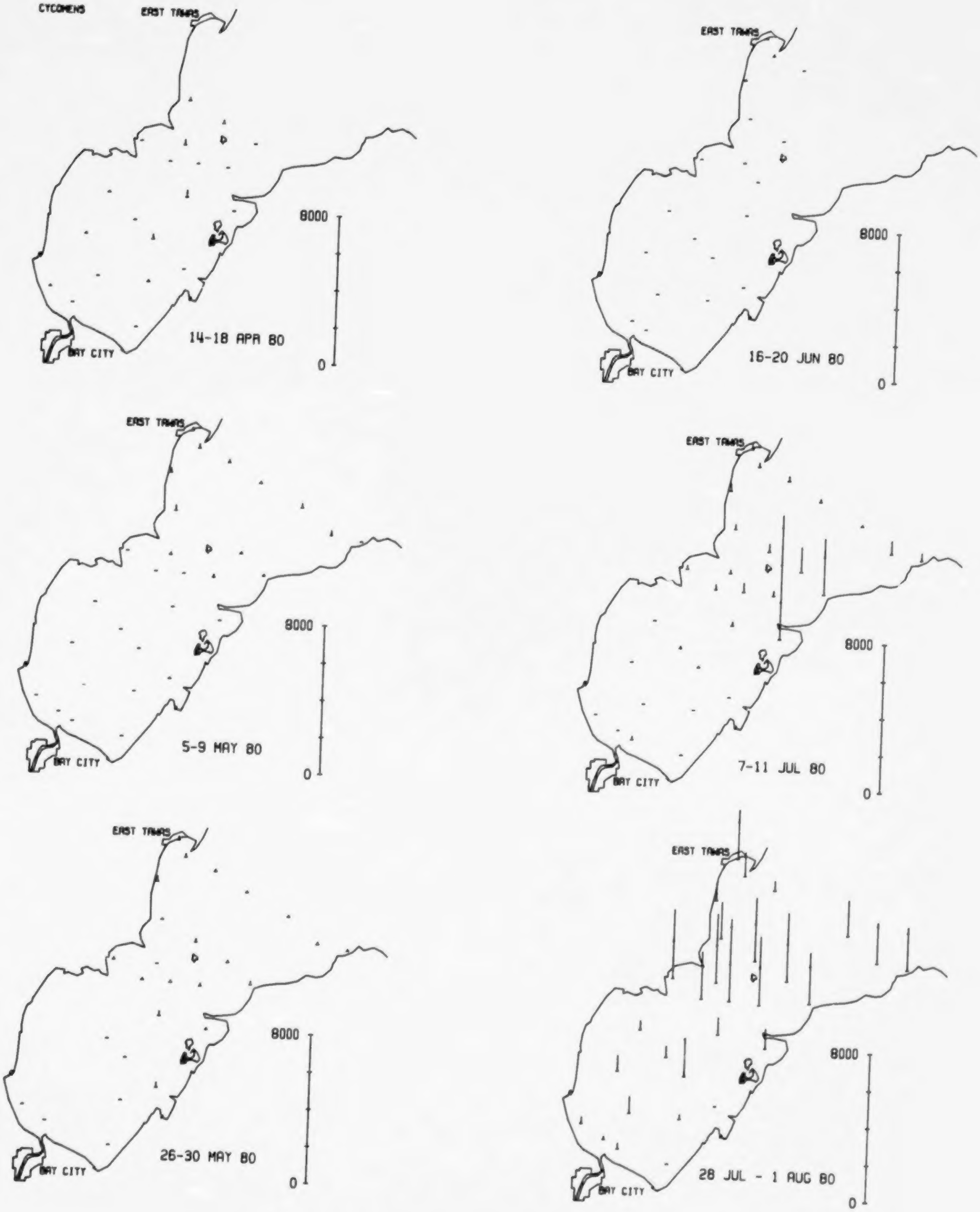

CYCOMENS
EAST TAWAS
BAY CITY
14-18 APR 80
8000
0
16-20 JUN 80
5-9 MAY 80
7-11 JUL 80
26-30 MAY 80
28 JUL - 1 AUG 80

Figure 23. Distribution of Cyclotella comensis.

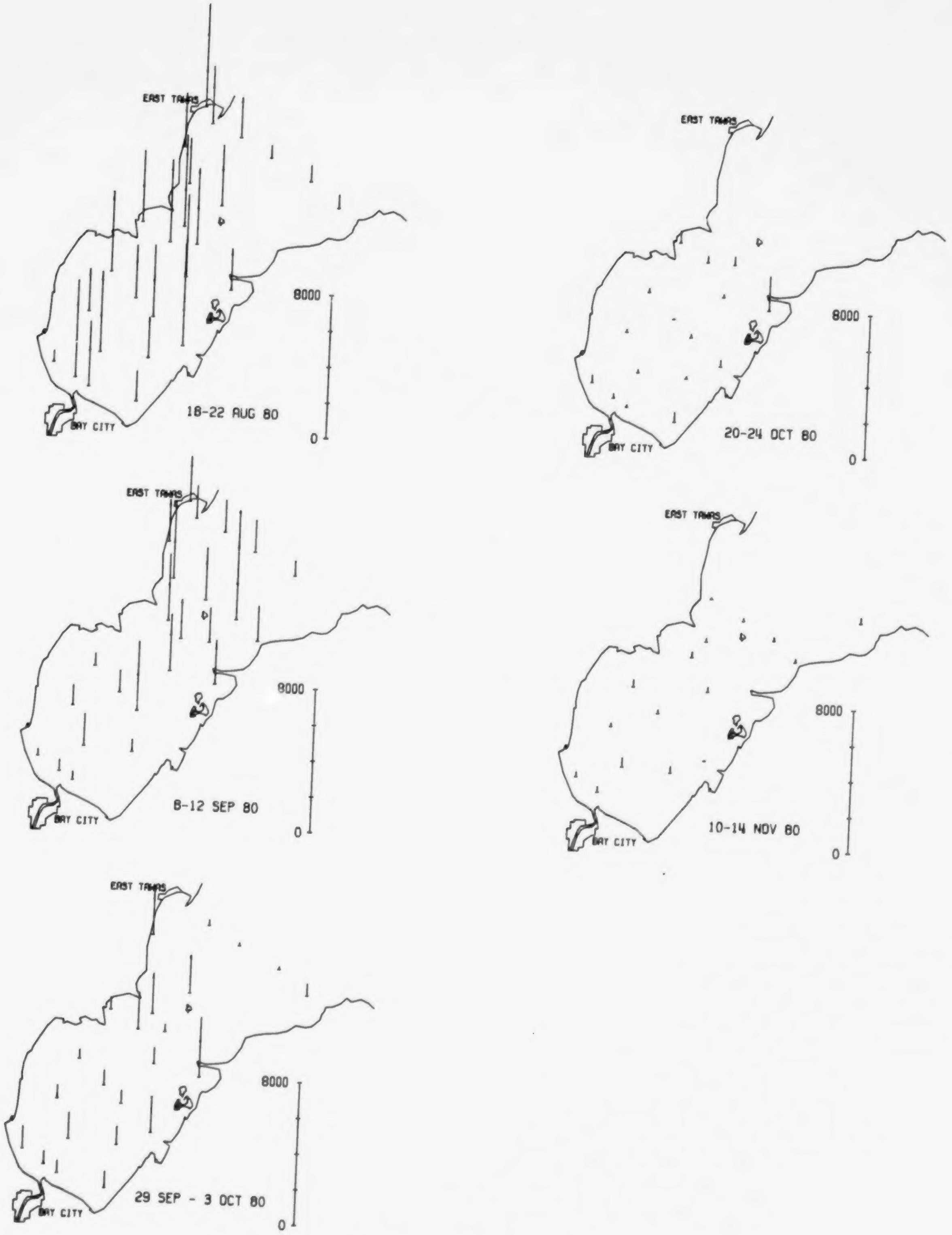

EAST TAWAS
8000
0
BAY CITY
18-22 AUG 80
EAST TAWAS
8000
0
BAY CITY
20-24 OCT 80
EAST TAWAS
8000
0
BAY CITY
8-12 SEP 80
EAST TAWAS
8000
0
BAY CITY
10-14 NOV 80
EAST TAWAS
8000
0
BAY CITY
29 SEP - 3 OCT 80

Figure 23. (continued).

Cyclotella comta (Figure 24)

This species is a member of the classical oligotrophic *Cyclotella* association (Hutchinson 1967). It is apparently tolerant of moderate levels of eutrophication but is absent from areas of the Great Lakes which have been excessively disturbed (Hohn 1969, Duthie and Sreenivasa 1971). In Saginaw Bay, it occurs in April and May but in very low densities. It is absent from the Bay in June and in July occurs only at the Bay-Lake Huron interface stations. Populations begin to increase again in late July, especially in the region around East Tawas. By September, it has reached its apparent maximum and numbers are declining by October. During summer months its distribution is generally limited to the middle and outer Bay. In spring and fall, sporadic occurrences are recorded from the inner Bay.

*Cyclotella meneghenia*na (Figure 25)

This centric diatom is distinctly riverine in its distribution and this is reflected in sample from Saginaw Bay. Absent from all stations in April, it occurred in the River on all cruises thereafter. Besides the River, the only stations to have significant populations were Stations 2, 7, 8, and 12 at the mouth of the River. A large pulse developed in July, densities declined in early August, and then remained moderately high through early October. Low levels persisted in the River area through November.

Cyclotella ocellata (Figure 26)

This species is an important component of phytoplankton assemblages in oligotrophic areas of the Great Lakes. In Saginaw Bay it reaches its greatest

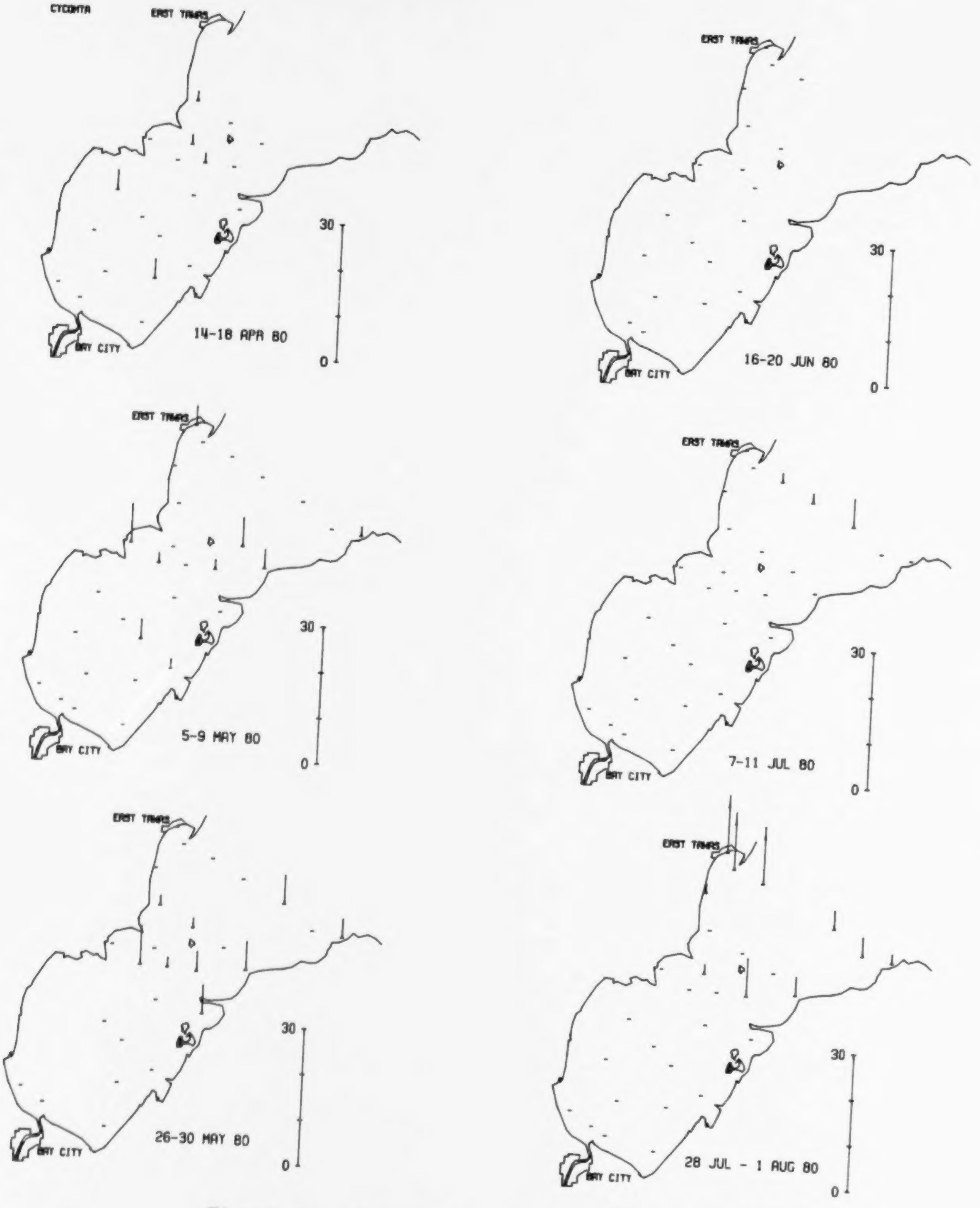

CYCOMTA
EAST TAWAS
BAY CITY
14-18 APR 80
30
0
EAST TAWAS
BAY CITY
16-20 JUN 80
30
0
EAST TAWAS
BAY CITY
5-9 MAY 80
30
0
EAST TAWAS
BAY CITY
7-11 JUL 80
30
0
EAST TAWAS
BAY CITY
26-30 MAY 80
30
0
EAST TAWAS
BAY CITY
28 JUL - 1 AUG 80
30
0

Figure 24. Distribution of Cyclotella comta.

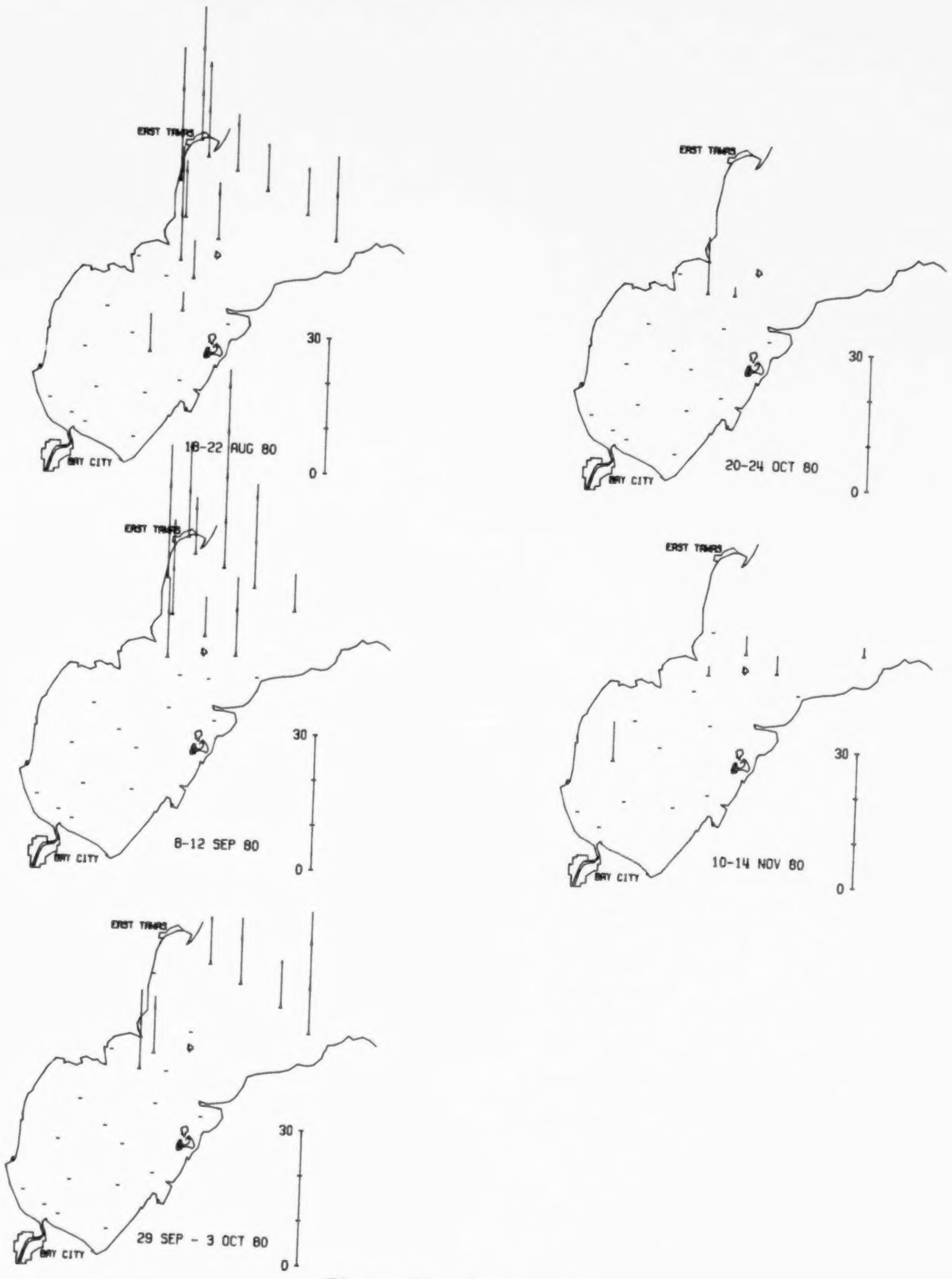

EAST TAWAS
BAY CITY
18-22 AUG 80
30
0
EAST TAWAS
BAY CITY
20-24 OCT 80
30
0
EAST TAWAS
BAY CITY
8-12 SEP 80
30
0
EAST TAWAS
BAY CITY
10-14 NOV 80
30
0
EAST TAWAS
BAY CITY
29 SEP - 3 OCT 80
30
0

Figure 24. (continued).

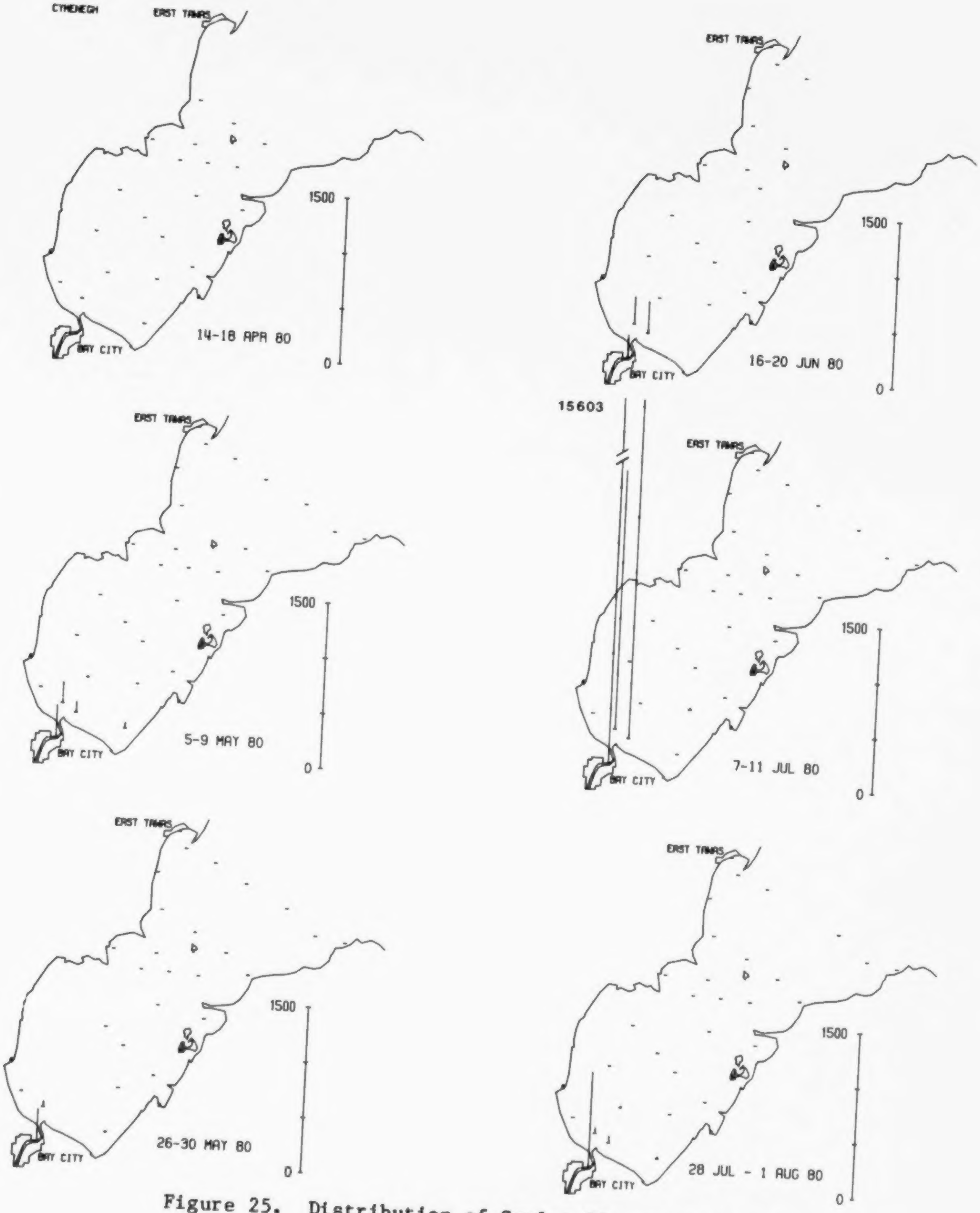

CYMENEGH
EAST TAWAS
BAY CITY
1500
0
14-18 APR 80
16-20 JUN 80
5-9 MAY 80
15603
7-11 JUL 80
26-30 MAY 80
28 JUL - 1 AUG 80

Figure 25. Distribution of Cyclotella meneghiniana.

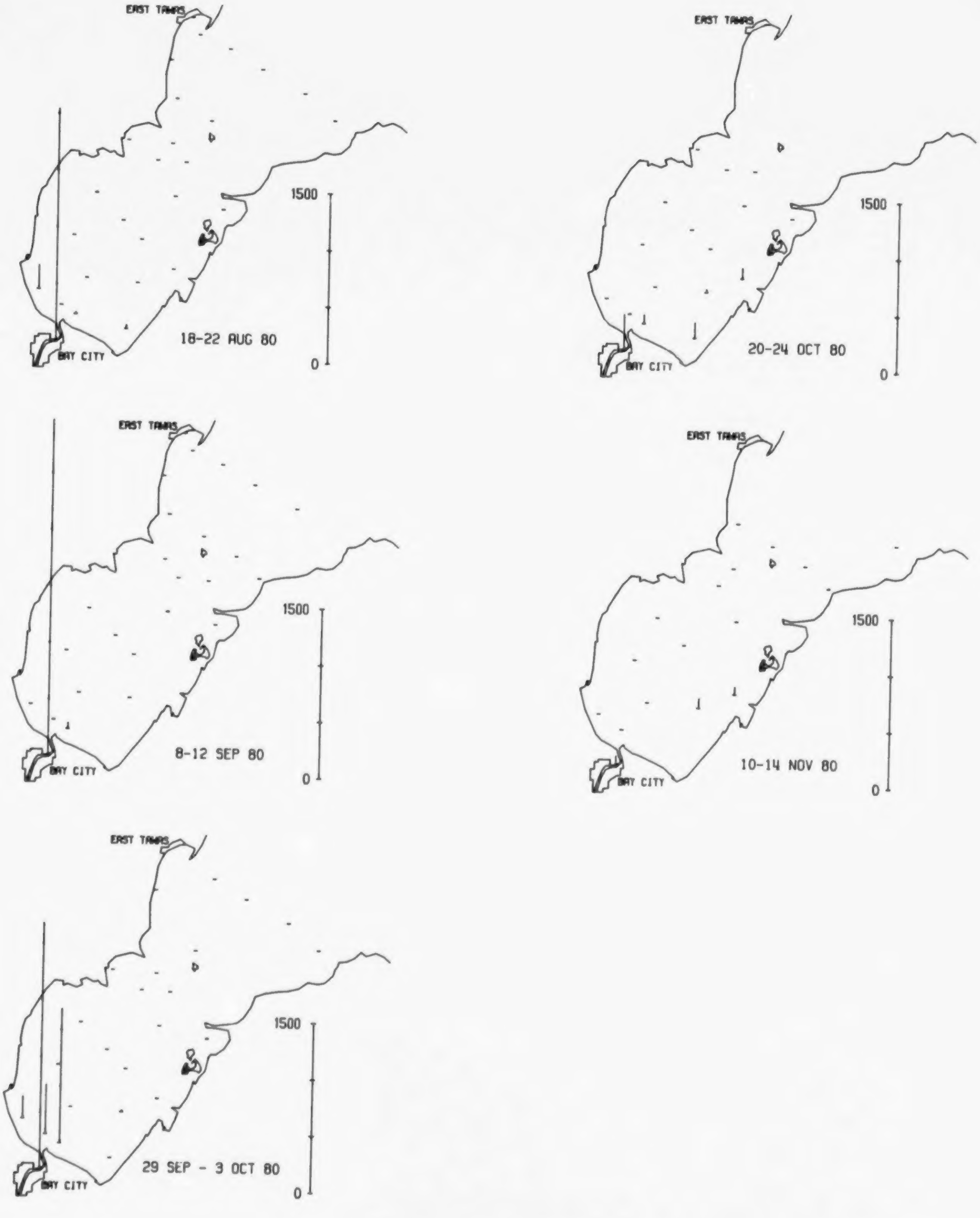

EAST TAWAS
BAY CITY
1500
0
18-22 AUG 80
20-24 OCT 80
8-12 SEP 80
10-14 NOV 80
29 SEP - 3 OCT 80

Figure 25. (continued).

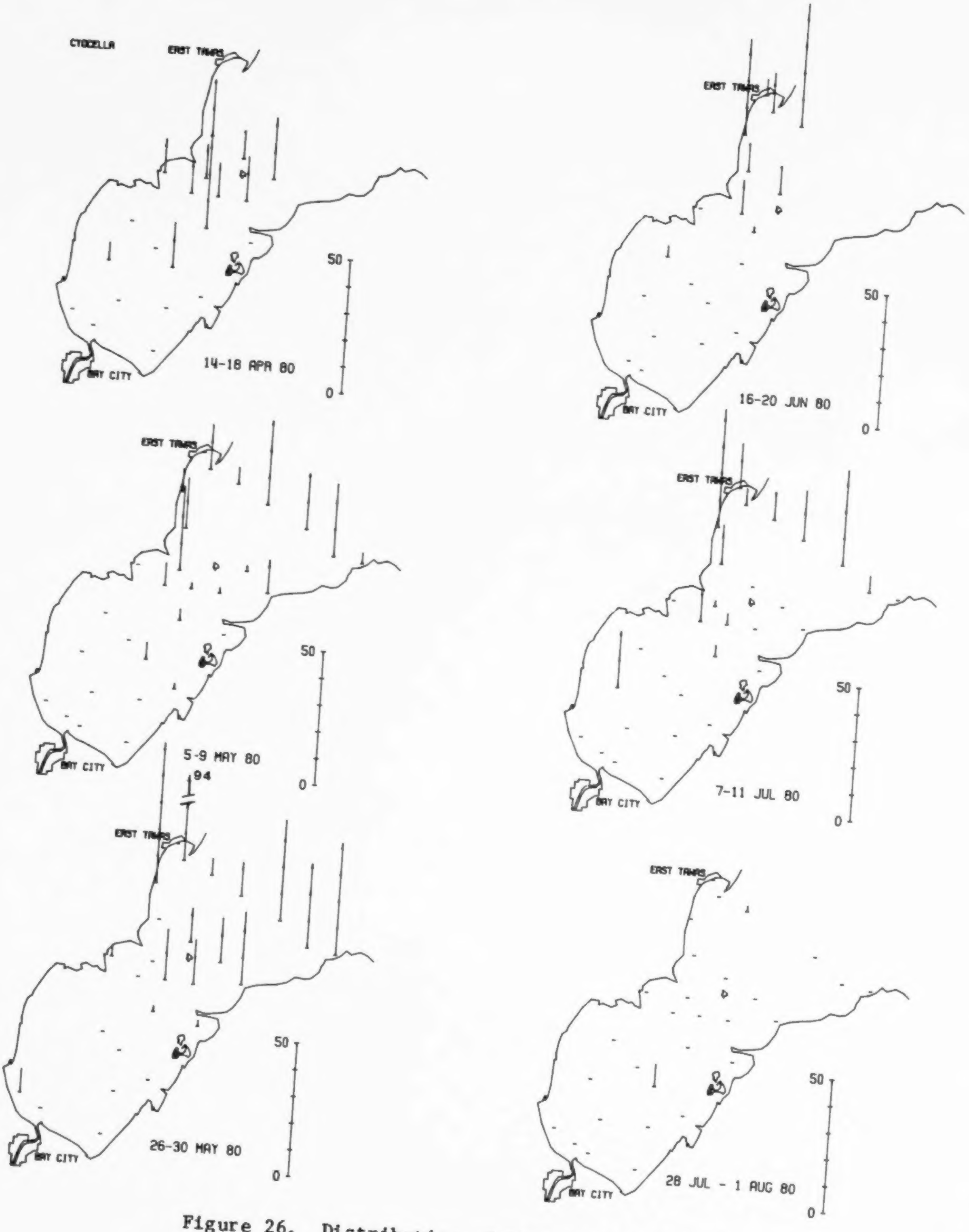

CYOCELLA
EAST TAWAS
BAY CITY
14-18 APR 80
50
0
EAST TAWAS
BAY CITY
16-20 JUN 80
50
0
EAST TAWAS
BAY CITY
5-9 MAY 80
50
0
EAST TAWAS
BAY CITY
7-11 JUL 80
50
0
94
EAST TAWAS
BAY CITY
26-30 MAY 80
50
0
EAST TAWAS
BAY CITY
28 JUL - 1 AUG 80
50
0

Figure 26. Distribution of Cyclotella ocellata.

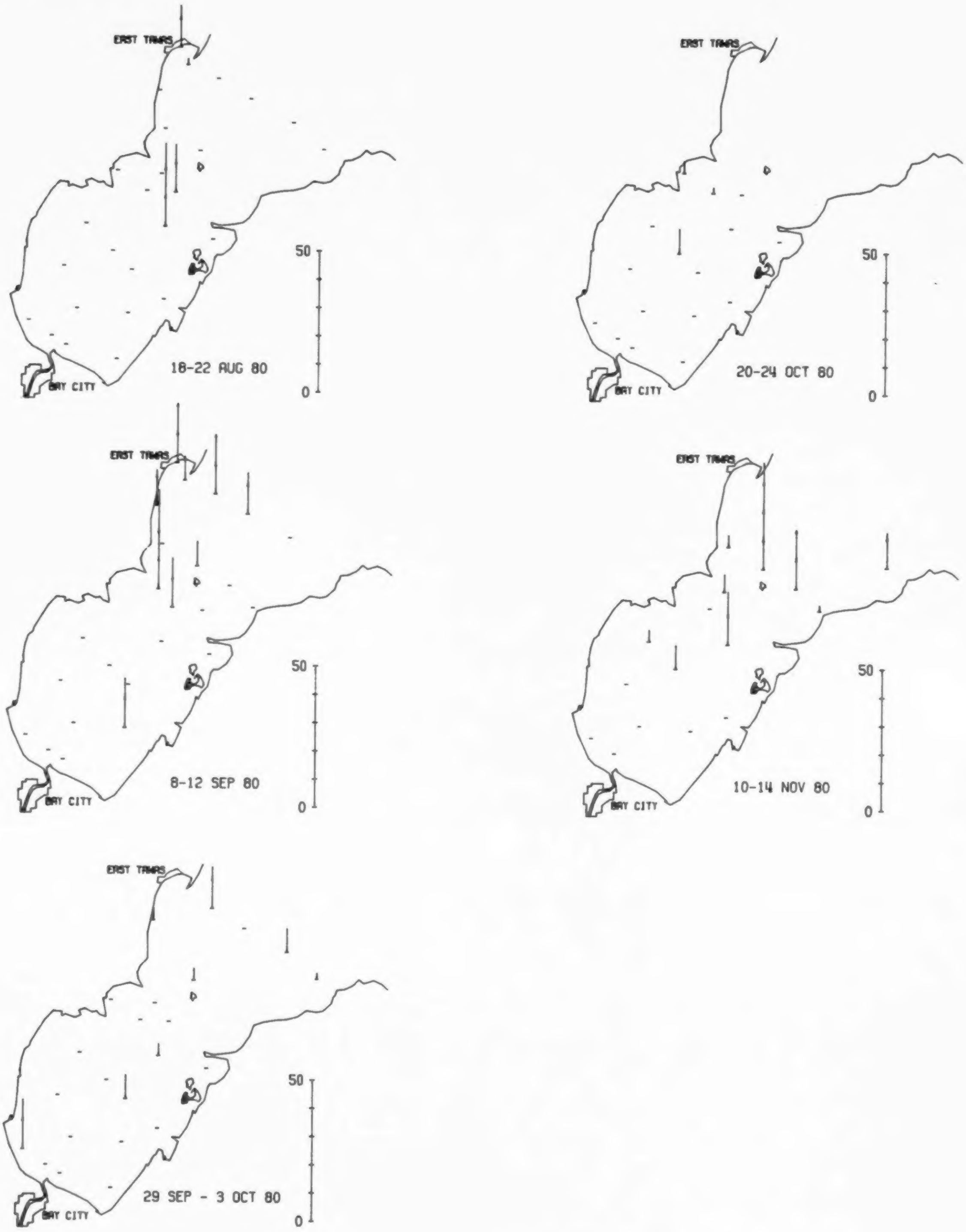

EAST TAWAS
BAY CITY
18-22 AUG 80
50
0
EAST TAWAS
BAY CITY
20-24 OCT 80
50
0
EAST TAWAS
BAY CITY
8-12 SEP 80
50
0
EAST TAWAS
BAY CITY
10-14 NOV 80
50
0
EAST TAWAS
BAY CITY
29 SEP - 3 OCT 80
50
0

Figure 26. (continued).

abundance in the middle and outer Bay in the spring and fall. In the inner Bay it occurs only sporadically and never in great abundance.

Cyclotella pseudostelligera (Figure 27)

This is a small centric diatom with distinct riverine affinities. Like C. meneghenlana, this species reaches high abundance levels in or near the Saginaw River and it is persistent through all seasons. It is more widely distributed in the Bay than is C. meneghenlana, occurring sporadically in nearshore areas in the middle Bay around Charity Island. However, cell densities of this species away from the Saginaw River are always very low.

Fragilaria capucina (Figure 28)

Although this species is most commonly reported from small eutrophic lakes, it can become a dominant in eutrophied portions of the Great Lakes (Hohn 1969). In terms of cell densities, it is by far the dominant diatom in Saginaw Bay on an annual basis; and, through most of the year, it is the most abundant of all phytoplankton species. In April, significant populations develop in the middle Bay. Cell densities increase mainly in the middle and outer Bay through May, with stations near the Saginaw River developing relatively high levels in April and May. Inner Bay stations reach a population maximum by June. Afterwards, numbers and distribution decline slightly through August. Another large pulse then develops, mainly on the western side of the Bay, and persists through November.

Fragilaria crotonensis (Figure 29)

This species is one of the most widely distributed and apparently

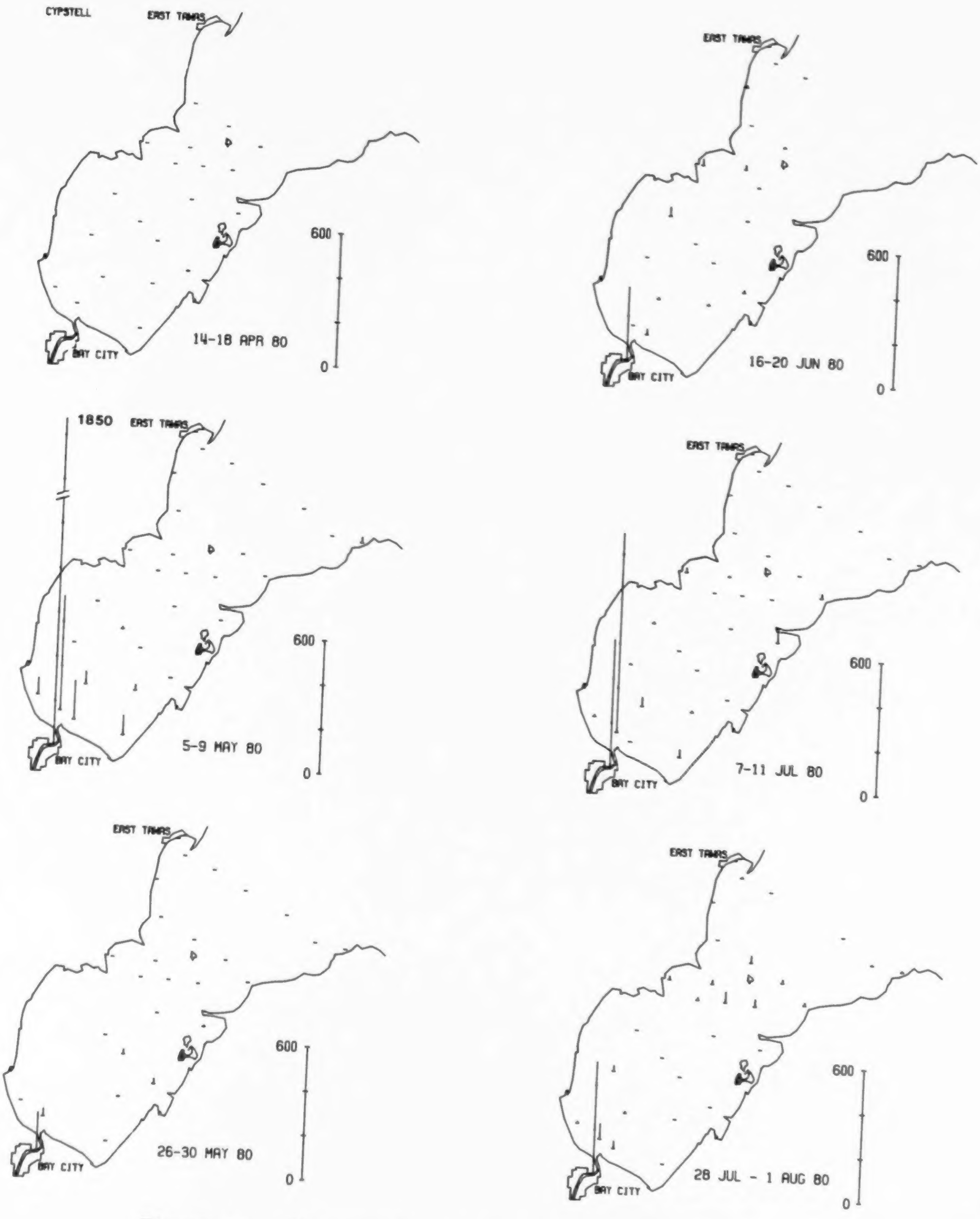

CYPSTELL
EAST TAWAS
BAY CITY
14-18 APR 80
600
0
EAST TAWAS
BAY CITY
16-20 JUN 80
600
0
1850
EAST TAWAS
BAY CITY
5-9 MAY 80
600
0
EAST TAWAS
BAY CITY
7-11 JUL 80
600
0
EAST TAWAS
BAY CITY
26-30 MAY 80
600
0
EAST TAWAS
BAY CITY
28 JUL - 1 AUG 80
600
0

Figure 27. Distribution of Cyclotella pseudostelligera.

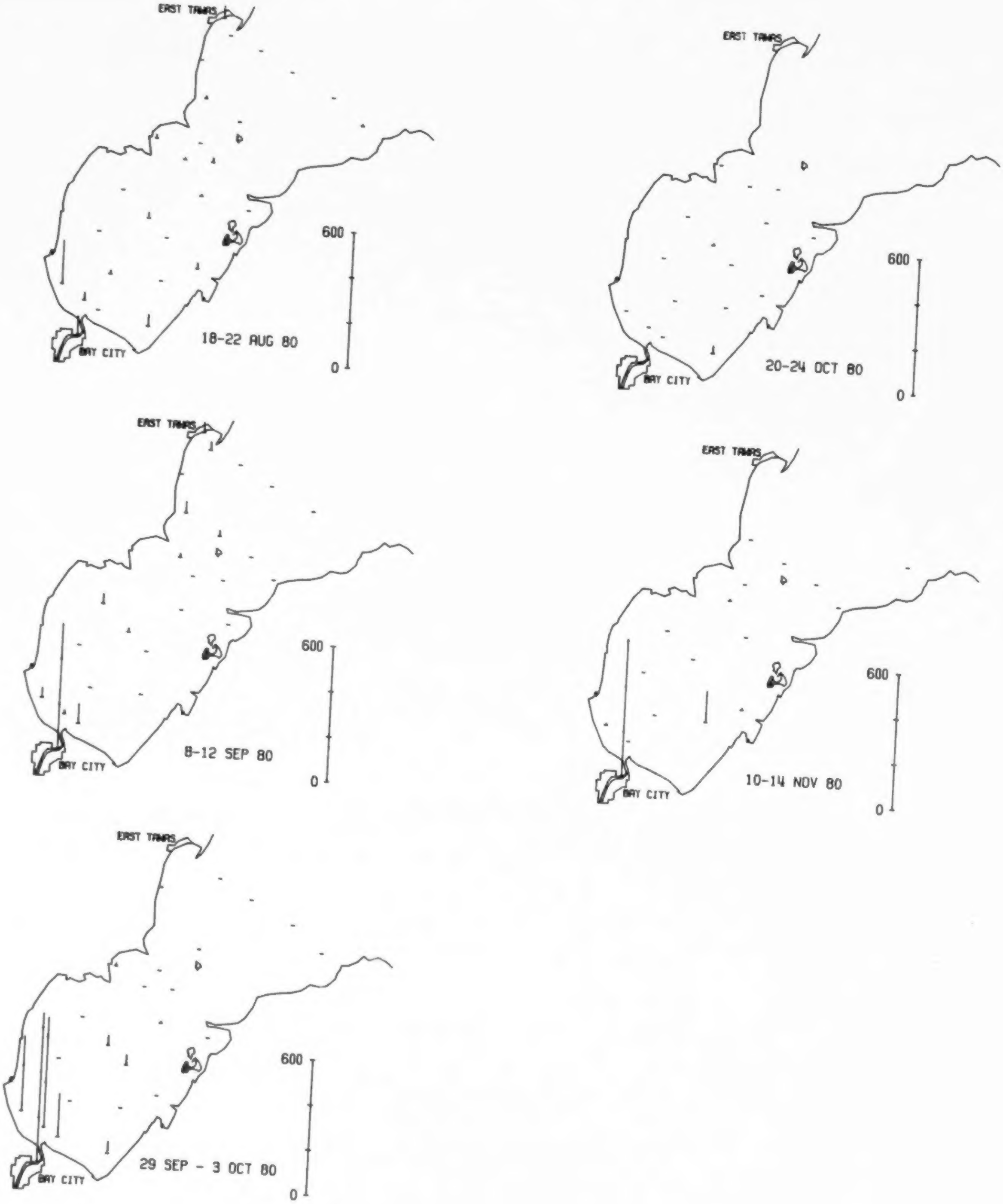

EAST TAWAS
BAY CITY
18-22 AUG 80
600
0
EAST TAWAS
BAY CITY
20-24 OCT 80
600
0
EAST TAWAS
BAY CITY
8-12 SEP 80
600
0
EAST TAWAS
BAY CITY
10-14 NOV 80
600
0
EAST TAWAS
BAY CITY
29 SEP - 3 OCT 80
600
0

Figure 27. (continued).

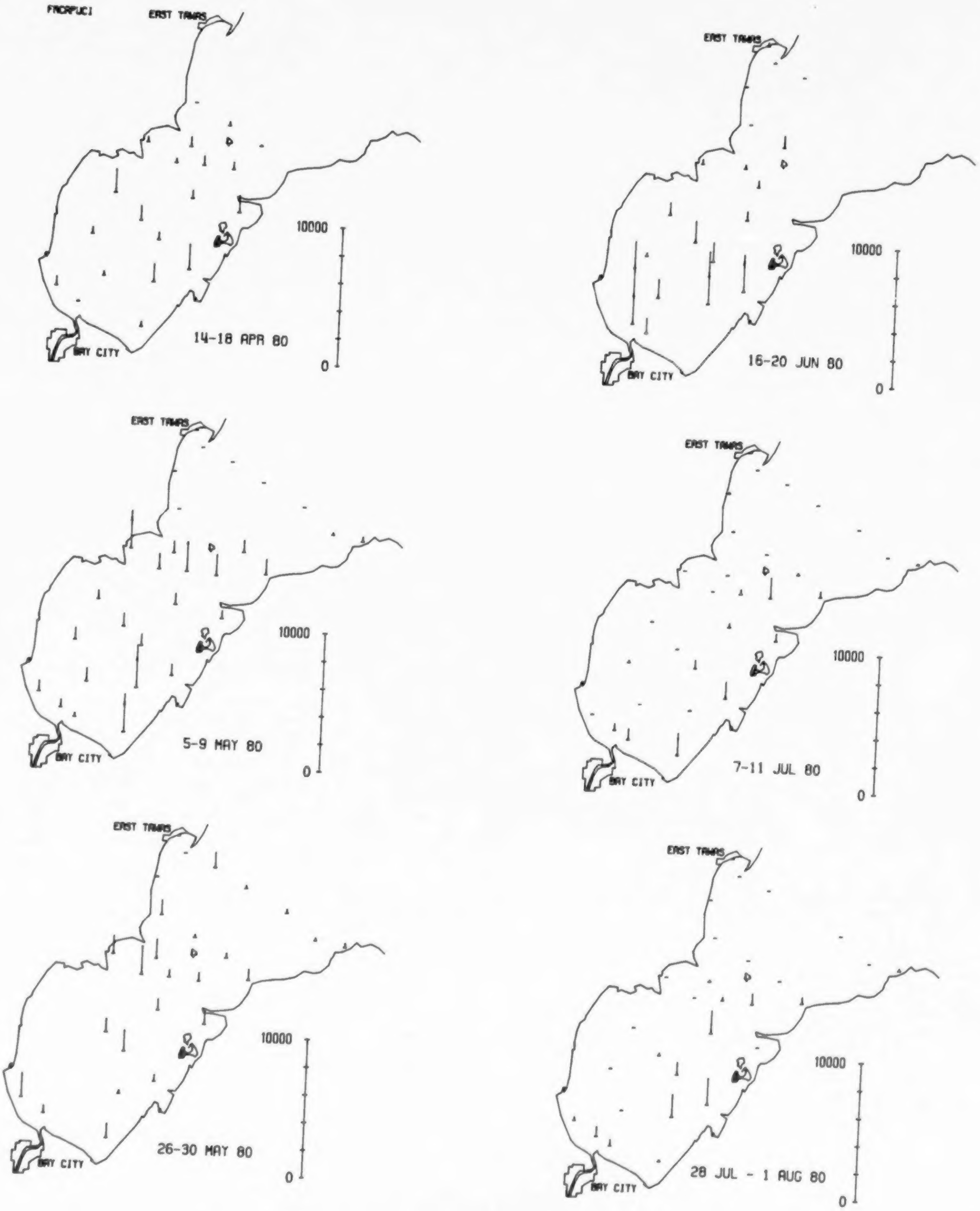

FRCAPUCI
EAST TAWAS
BAY CITY
14-18 APR 80
10000
0
EAST TAWAS
BAY CITY
16-20 JUN 80
10000
0
EAST TAWAS
BAY CITY
5-9 MAY 80
10000
0
EAST TAWAS
BAY CITY
7-11 JUL 80
10000
0
EAST TAWAS
BAY CITY
26-30 MAY 80
10000
0
EAST TAWAS
BAY CITY
28 JUL - 1 AUG 80
10000
0

Figure 28. Distribution of Fragilaria capucina.

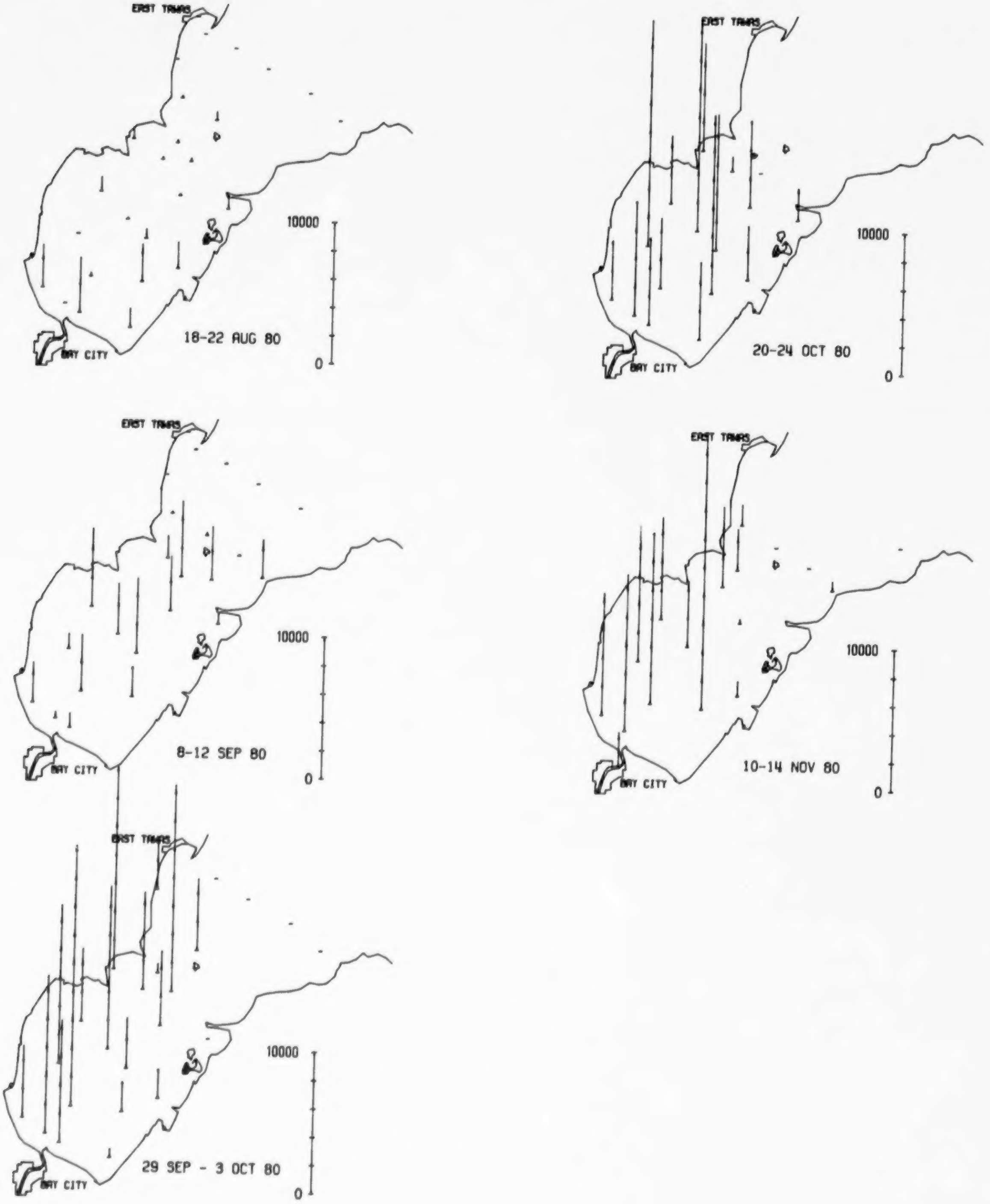

EAST TAWAS
BAY CITY
10000
0
18-22 AUG 80
EAST TAWAS
BAY CITY
10000
0
20-24 OCT 80
EAST TAWAS
BAY CITY
10000
0
8-12 SEP 80
EAST TAWAS
BAY CITY
10000
0
10-14 NOV 80
EAST TAWAS
BAY CITY
10000
0
29 SEP - 3 OCT 80

Figure 28. (continued).

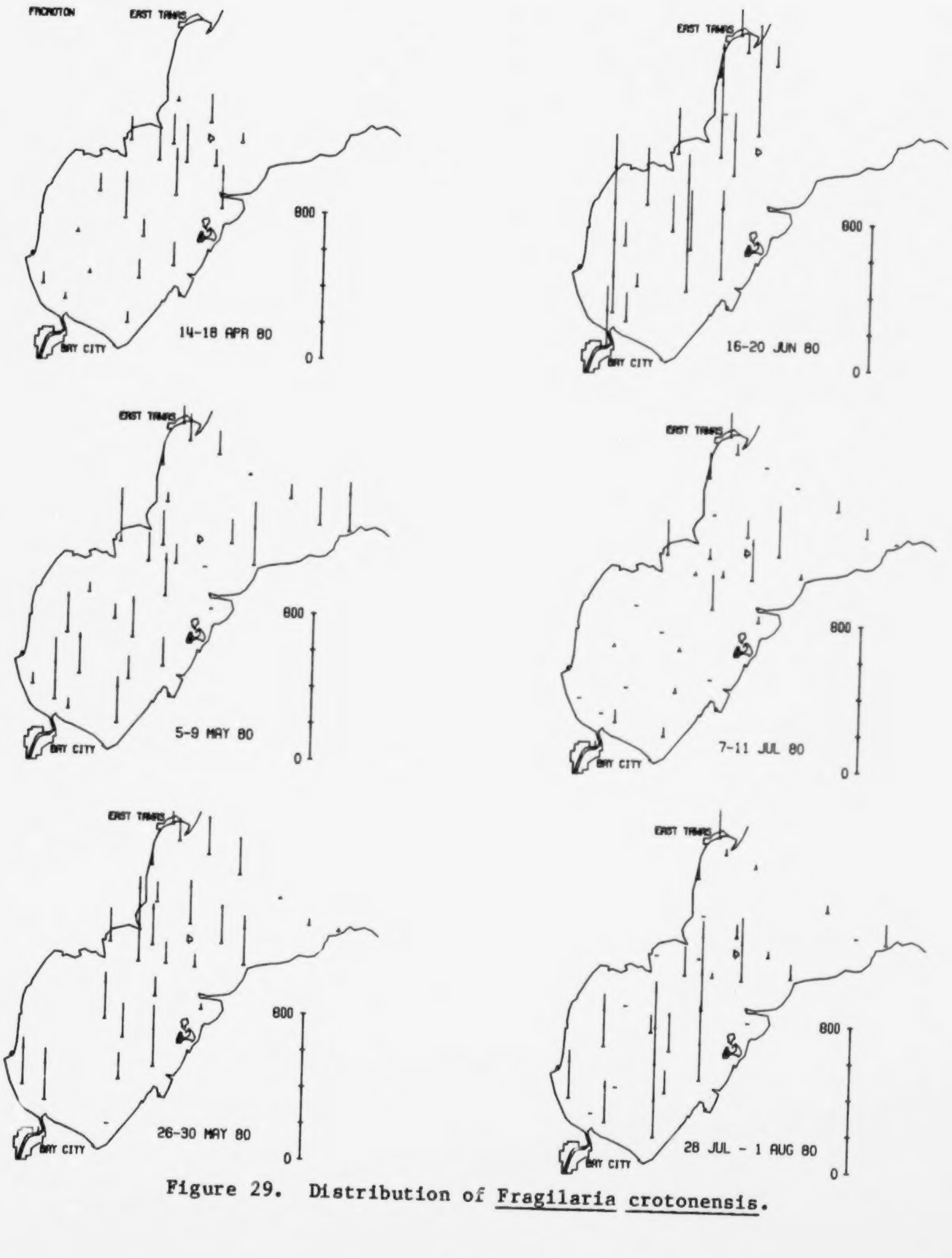

FRCROTON
EAST TAWAS
800
0
14-18 APR 80
BAY CITY
EAST TAWAS
800
0
16-20 JUN 80
BAY CITY
EAST TAWAS
800
0
5-9 MAY 80
BAY CITY
EAST TAWAS
800
0
7-11 JUL 80
BAY CITY
EAST TAWAS
800
0
26-30 MAY 80
BAY CITY
EAST TAWAS
800
0
28 JUL - 1 AUG 80
BAY CITY

Figure 29. Distribution of Fragilaria crotonensis.

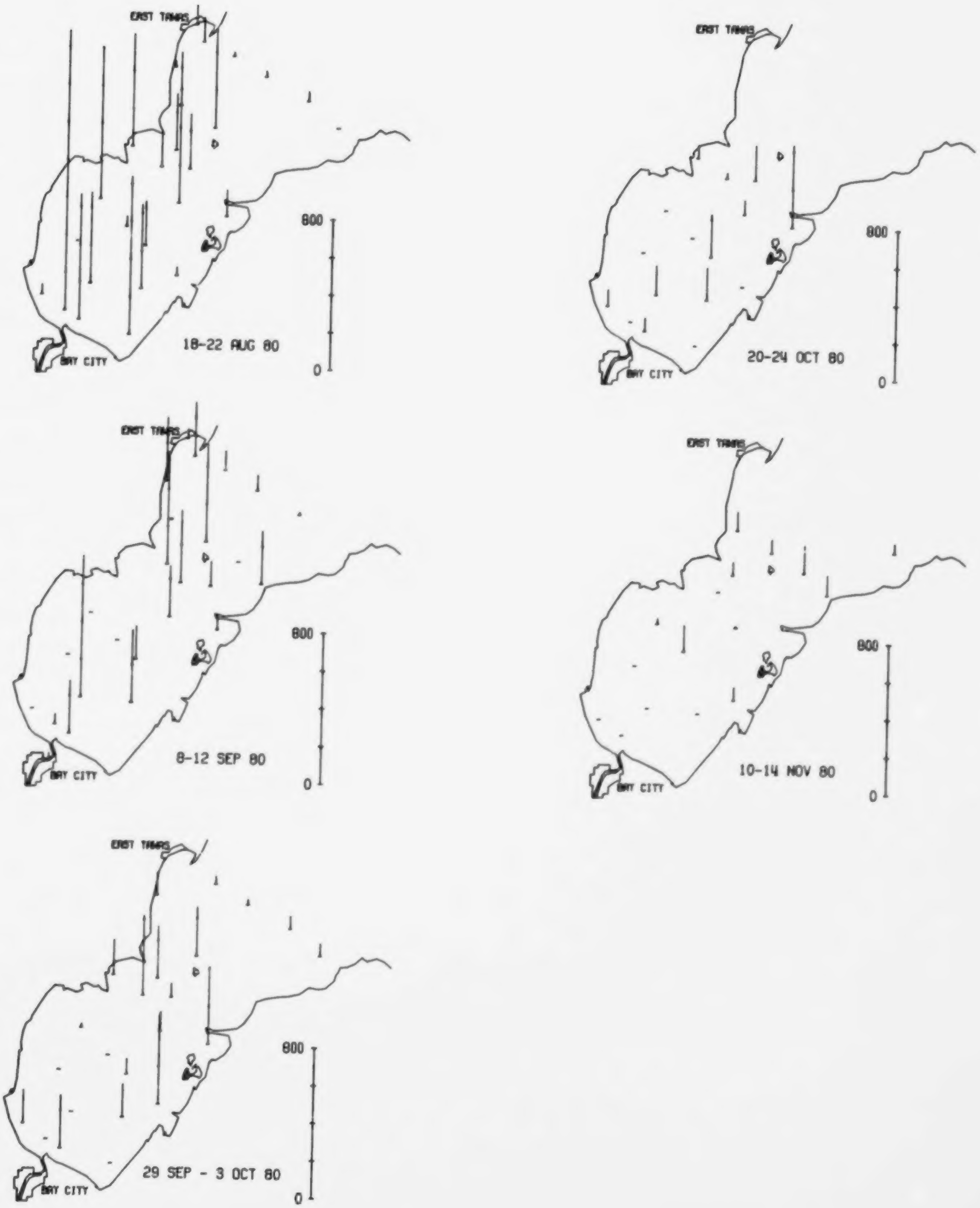

EAST TAWAS
BAY CITY
800
0
18-22 AUG 80
EAST TAWAS
BAY CITY
800
0
20-24 OCT 80
EAST TAWAS
BAY CITY
800
0
8-12 SEP 80
EAST TAWAS
BAY CITY
800
0
10-14 NOV 80
EAST TAWAS
BAY CITY
800
0
29 SEP - 3 OCT 80

Figure 29. (continued).

eurytopic of all freshwater diatoms. It is common throughout the entire Great Lakes system. It responds strongly to experimental phosphorus enrichment (Stoermer, Ladewski, and Schelske 1978), but is abundant in areas which characteristically have low ambient concentrations of this nutrient. In Saginaw Bay highest levels routinely occur in the middle Bay, indicating that its development is encouraged by moderate nutrient levels, but that it is not as tolerant of more disturbed environments. Its distribution and abundance are roughly uniform both seasonally and spatially in Saginaw Bay. Cell densities are moderately high in April, with maximum abundance occurring at the middle Bay stations. By June it has spread throughout the Bay, but abundance levels decline in nearshore areas in July and the largest populations are again found in the middle Bay. From August through early October it reaches its greatest densities in the middle and inner Bay, but remains a relatively important element of the stations at the mouth of the Bay. By November, populations have declined through most of the Bay with modest abundance levels remaining again at the middle Bay stations.

Melosira distans var. *alpigena* (Figure 30)

This species is a common component of phytoplankton assemblages of rivers and it is rarely reported from offshore waters of the Great Lakes. It reaches its maximum density in Saginaw Bay at Station 54 in the Saginaw River and at the stations at the mouth of the River. Sporadic occurrences of moderate levels of the species were found from nearshore and shallow water stations.

Melosira granulata (Figure 31)

This species generally reaches its highest abundance in small eutrophic

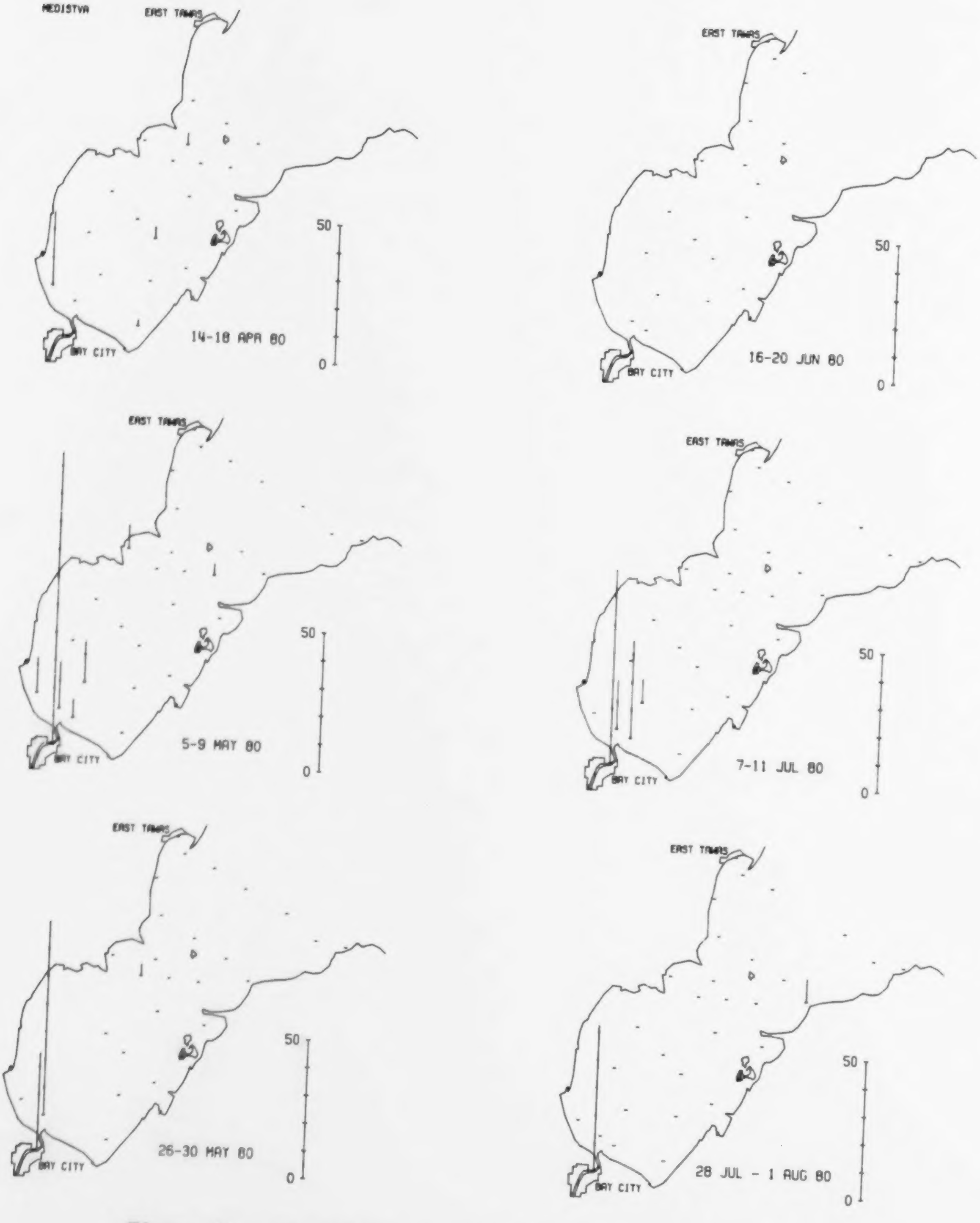

MEDISTVA
EAST TAWAS
BAY CITY
14-18 APR 80
50
0
EAST TAWAS
BAY CITY
16-20 JUN 80
50
0
EAST TAWAS
BAY CITY
5-9 MAY 80
50
0
EAST TAWAS
BAY CITY
7-11 JUL 80
50
0
EAST TAWAS
BAY CITY
26-30 MAY 80
50
0
EAST TAWAS
BAY CITY
28 JUL - 1 AUG 80
50
0

Figure 30. Distribution of Melosira distans var. alpigena.

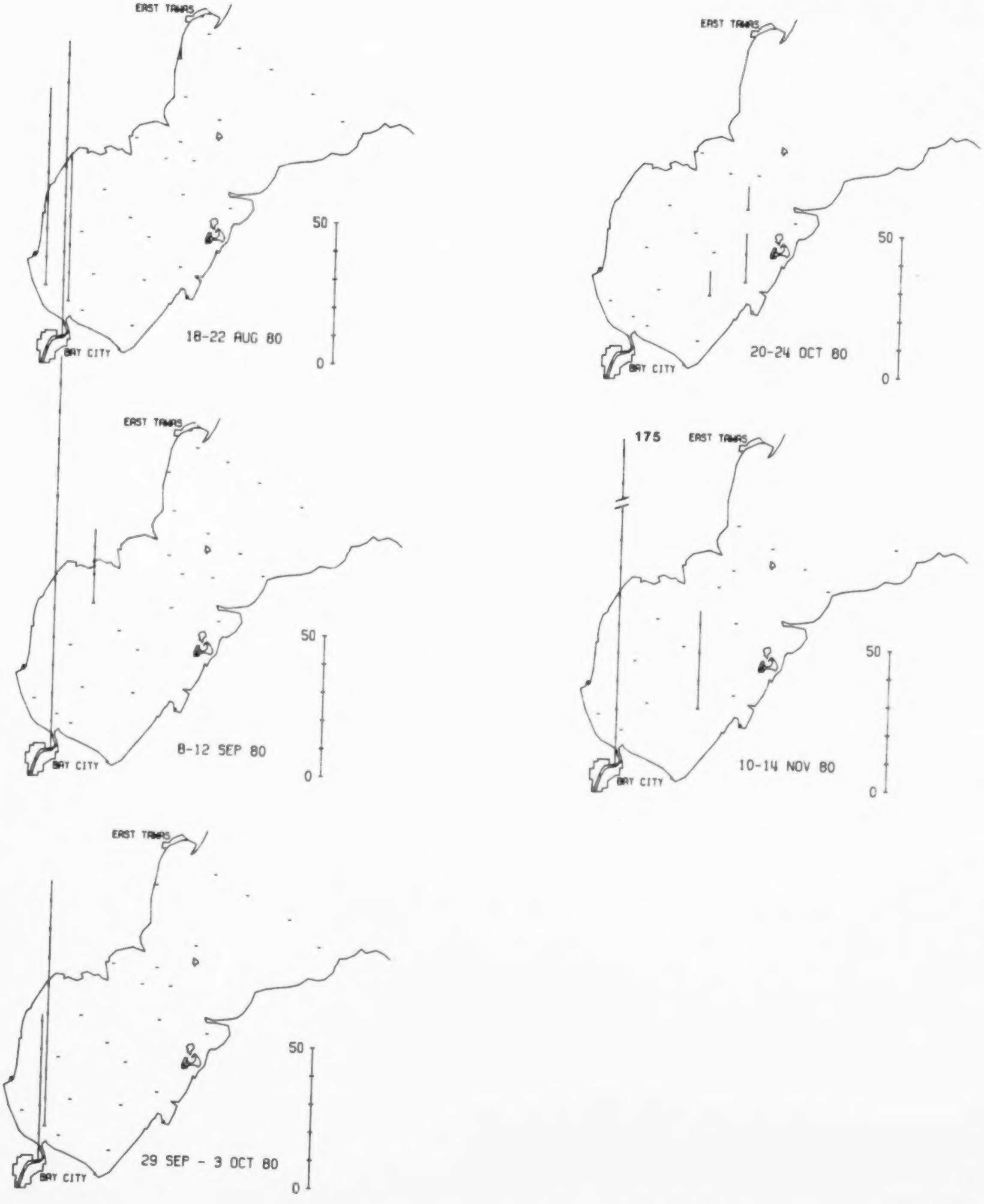

EAST TAWAS
BAY CITY
18-22 AUG 80
50
0
EAST TAWAS
BAY CITY
20-24 OCT 80
50
0
EAST TAWAS
BAY CITY
8-12 SEP 80
50
0
175
EAST TAWAS
BAY CITY
10-14 NOV 80
50
0
EAST TAWAS
BAY CITY
29 SEP - 3 OCT 80
50
0

Figure 30. (continued).

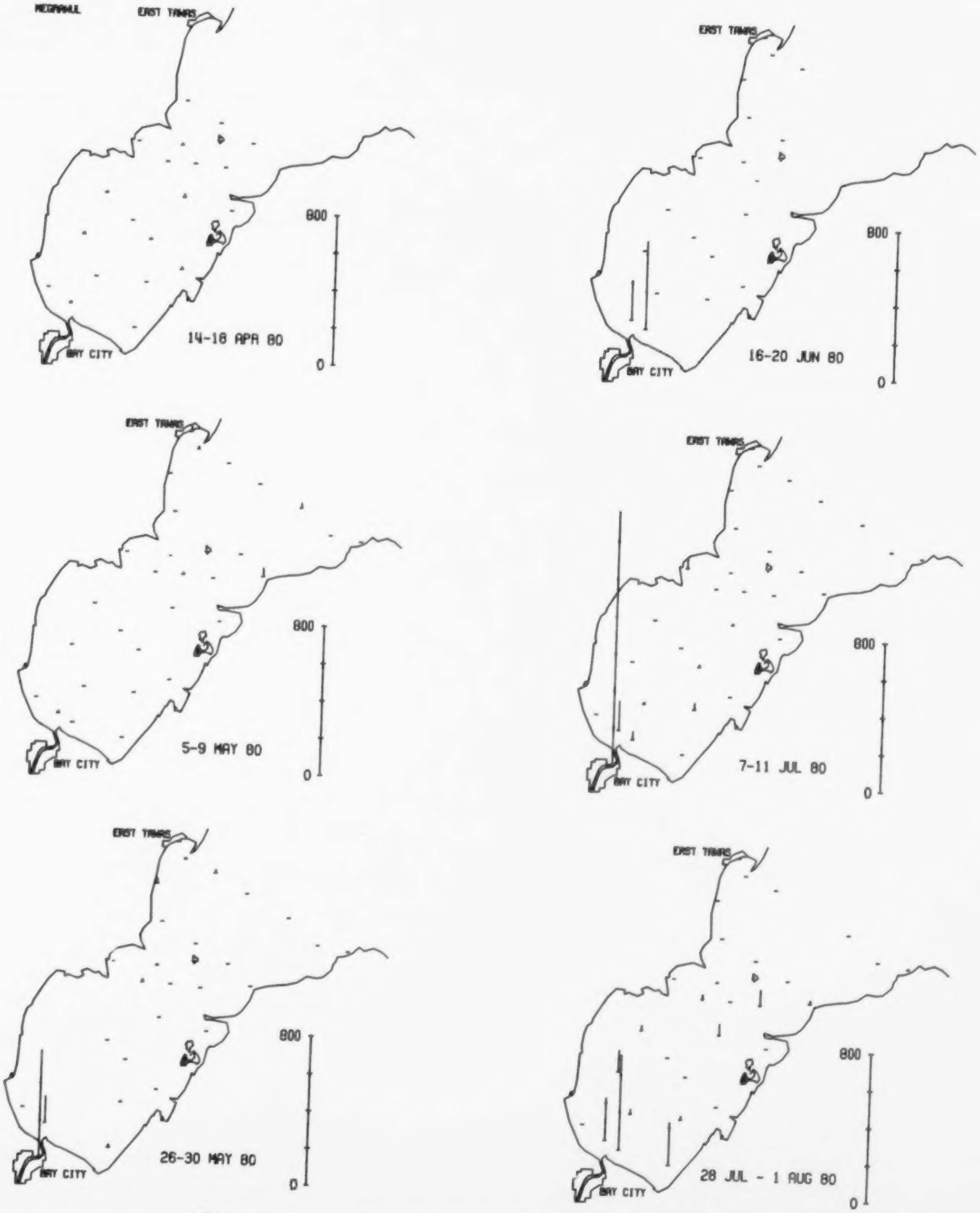

MEGRANUL
EAST TAWAS
800
0
14-18 APR 80
BAY CITY
EAST TAWAS
800
0
16-20 JUN 80
BAY CITY
EAST TAWAS
800
0
5-9 MAY 80
BAY CITY
EAST TAWAS
800
0
7-11 JUL 80
BAY CITY
EAST TAWAS
800
0
26-30 MAY 80
BAY CITY
EAST TAWAS
800
0
28 JUL - 1 AUG 80
BAY CITY

Figure 31. Distribution of Melosira granulata.

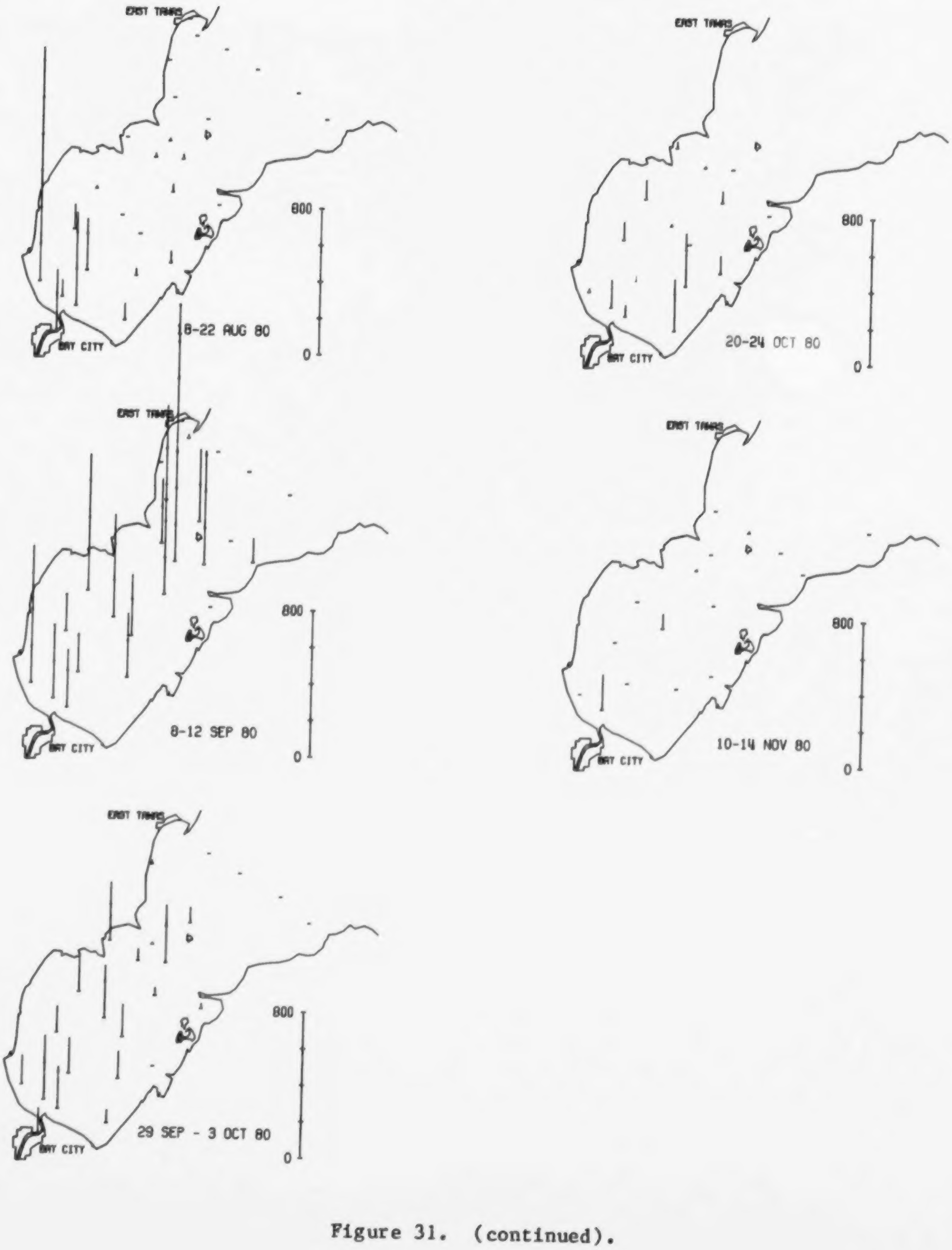

EAST TAWAS
BAY CITY
18-22 AUG 80
800
0
EAST TAWAS
BAY CITY
20-24 OCT 80
800
0
EAST TAWAS
BAY CITY
8-12 SEP 80
800
0
EAST TAWAS
BAY CITY
10-14 NOV 80
800
0
EAST TAWAS
BAY CITY
29 SEP - 3 OCT 80
800
0

Figure 31. (continued).

lakes where it often forms early summer blooms and early fall. It is common in shallow eutrophied areas of the Great Lakes and in the offshore waters of Lake Erie, but rarely, if ever, reaches high abundance levels in offshore waters of the other Great Lakes (Stoermer 1978). In Saginaw Bay it first appears in abundance in and near the Saginaw River. Its spatial distribution slowly increases until early September when it occurs in abundance throughout the Bay with the exception of the offshore stations at the mouth of the Bay. Population levels and distribution both decrease through November.

Melosira islandica (Figure 32)

This species is a common cold season dominant in boreal and alpine lakes worldwide. It is common throughout the Great Lakes system and appears to be favored by moderate levels of nutrient loading although it tends to disappear from grossly perturbed habitats. Its distribution in Saginaw Bay is in accord with these generalizations. In April and May it reached its greatest abundance at mid-Bay stations and was absent from stations near the Saginaw River. By late May, it occurred only at nearshore stations in the outer one-third of the Bay. In June a few cells were seen at East Tawas. It was absent from samples until November when outer Bay offshore stations showed a small pulse.

Stephanodiscus binderanus (Figure 33)

This species is a dominant element of highly disturbed areas of the Great Lakes and is commonly reported in spring blooms. It usually reaches its maximum abundance in nearshore areas during the thermal bar period (Nalewajko 1967, Loirface and Munawar 1974), but Stoermer *et al*. (1974) reported it from offshore waters in Lake Ontario and Hohn (1969) found it in offshore waters of

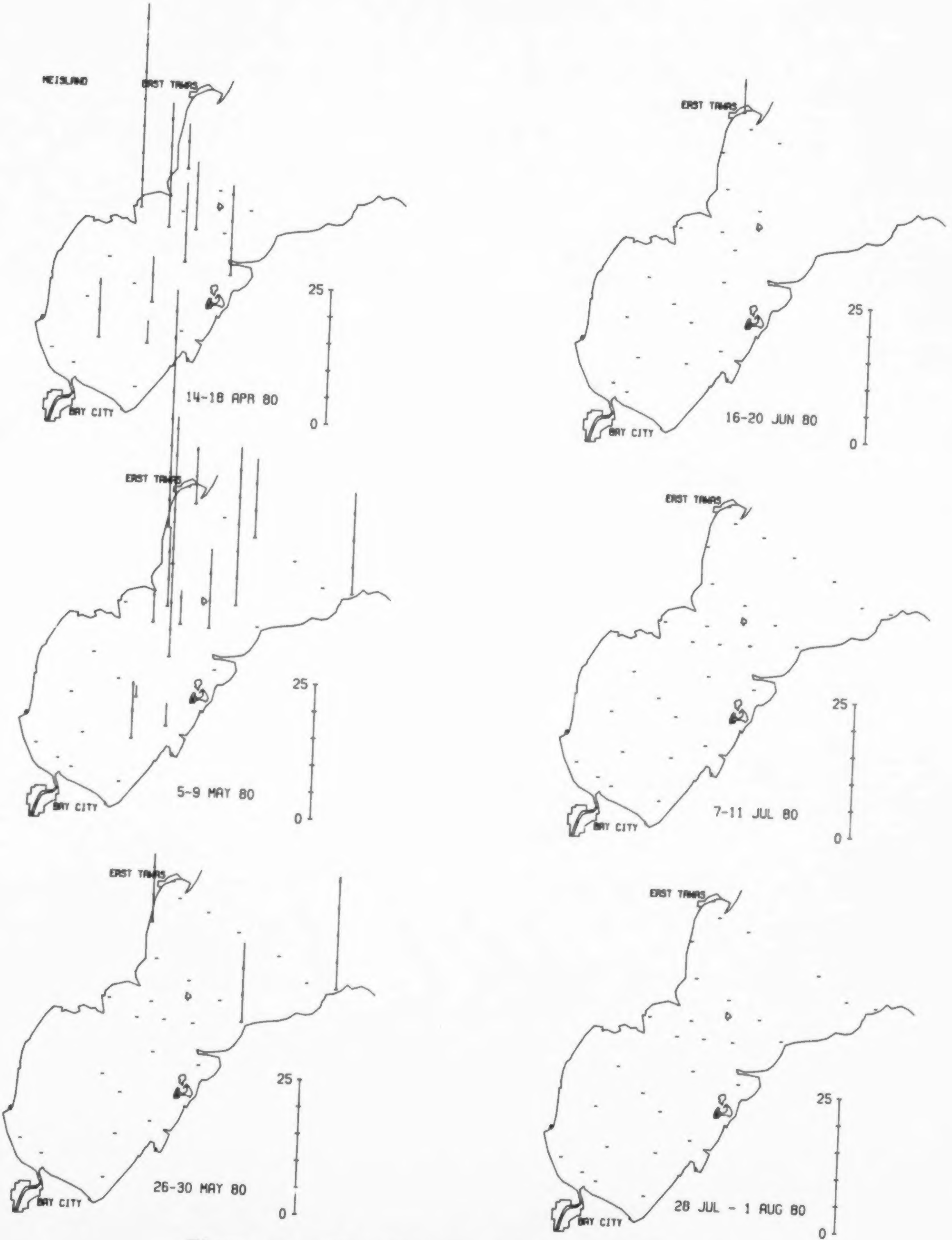

MEISLAND
EAST TAWAS
BAY CITY
14-18 APR 80
25
0
EAST TAWAS
BAY CITY
16-20 JUN 80
25
0
EAST TAWAS
BAY CITY
5-9 MAY 80
25
0
EAST TAWAS
BAY CITY
7-11 JUL 80
25
0
EAST TAWAS
BAY CITY
26-30 MAY 80
25
0
EAST TAWAS
BAY CITY
28 JUL - 1 AUG 80
25
0

Figure 32. Distribution of Melosira islandica.

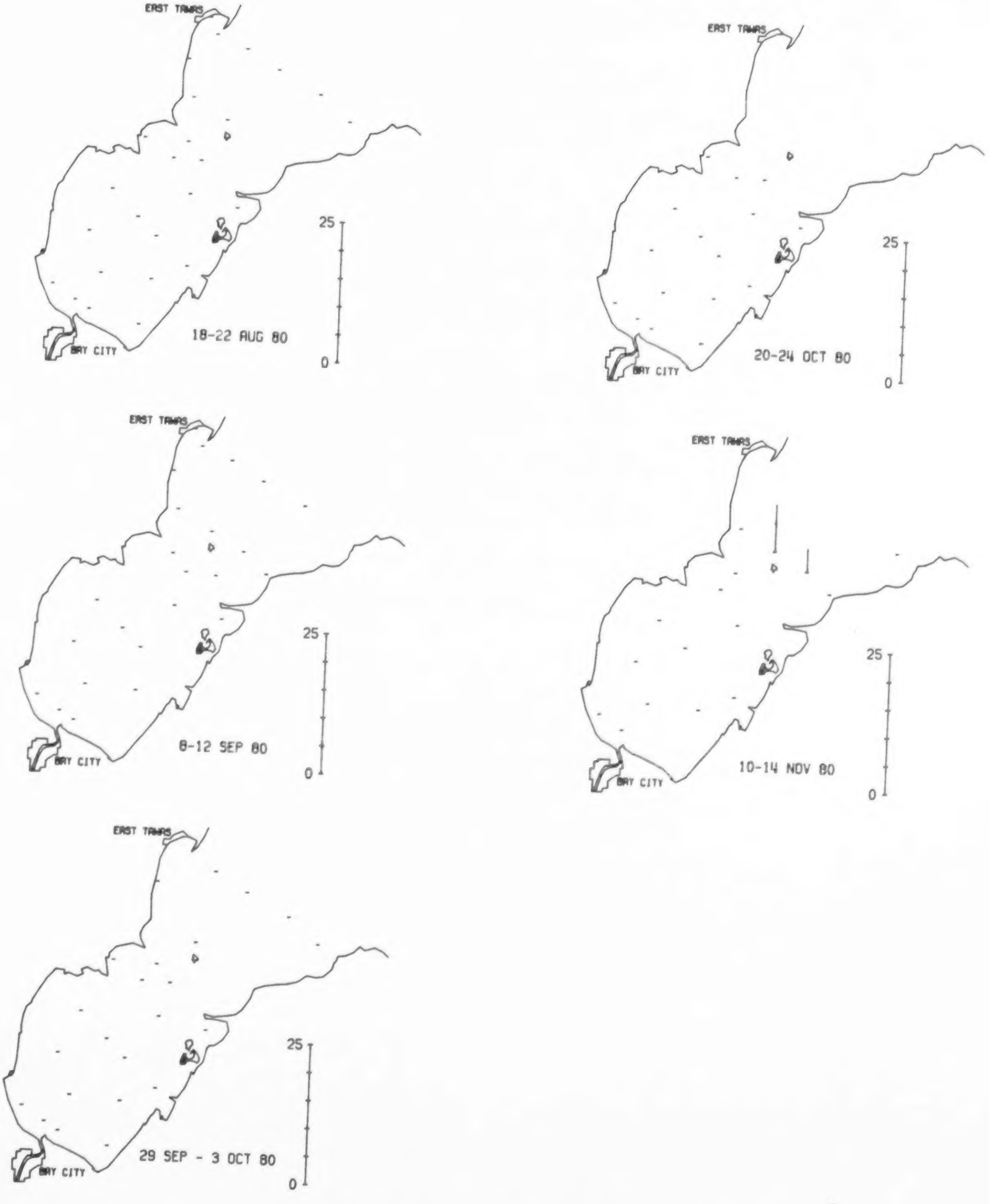

EAST TAWAS
BAY CITY
18-22 AUG 80
25
0
EAST TAWAS
BAY CITY
20-24 OCT 80
25
0
EAST TAWAS
BAY CITY
8-12 SEP 80
25
0
EAST TAWAS
BAY CITY
10-14 NOV 80
25
0
EAST TAWAS
BAY CITY
29 SEP - 3 OCT 80
25
0

Figure 32. (continued).

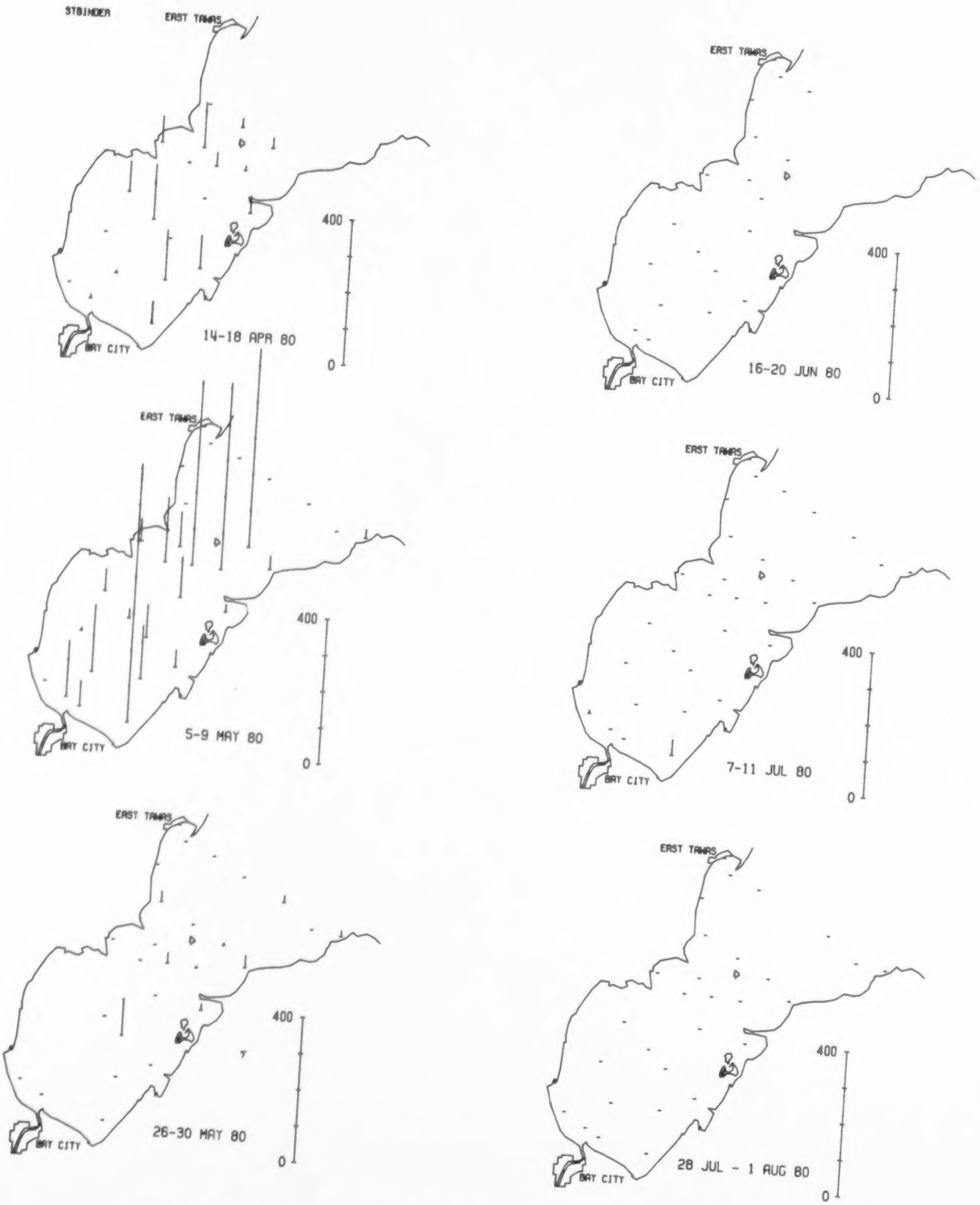

STBINDER
EAST TAWAS
BAY CITY
14-18 APR 80
400
0
EAST TAWAS
BAY CITY
16-20 JUN 80
400
0
EAST TAWAS
BAY CITY
5-9 MAY 80
400
0
EAST TAWAS
BAY CITY
7-11 JUL 80
400
0
EAST TAWAS
BAY CITY
26-30 MAY 80
400
0
EAST TAWAS
BAY CITY
28 JUL - 1 AUG 80
400
0

Figure 33. Distribution of Stephanodiscus binderanus.

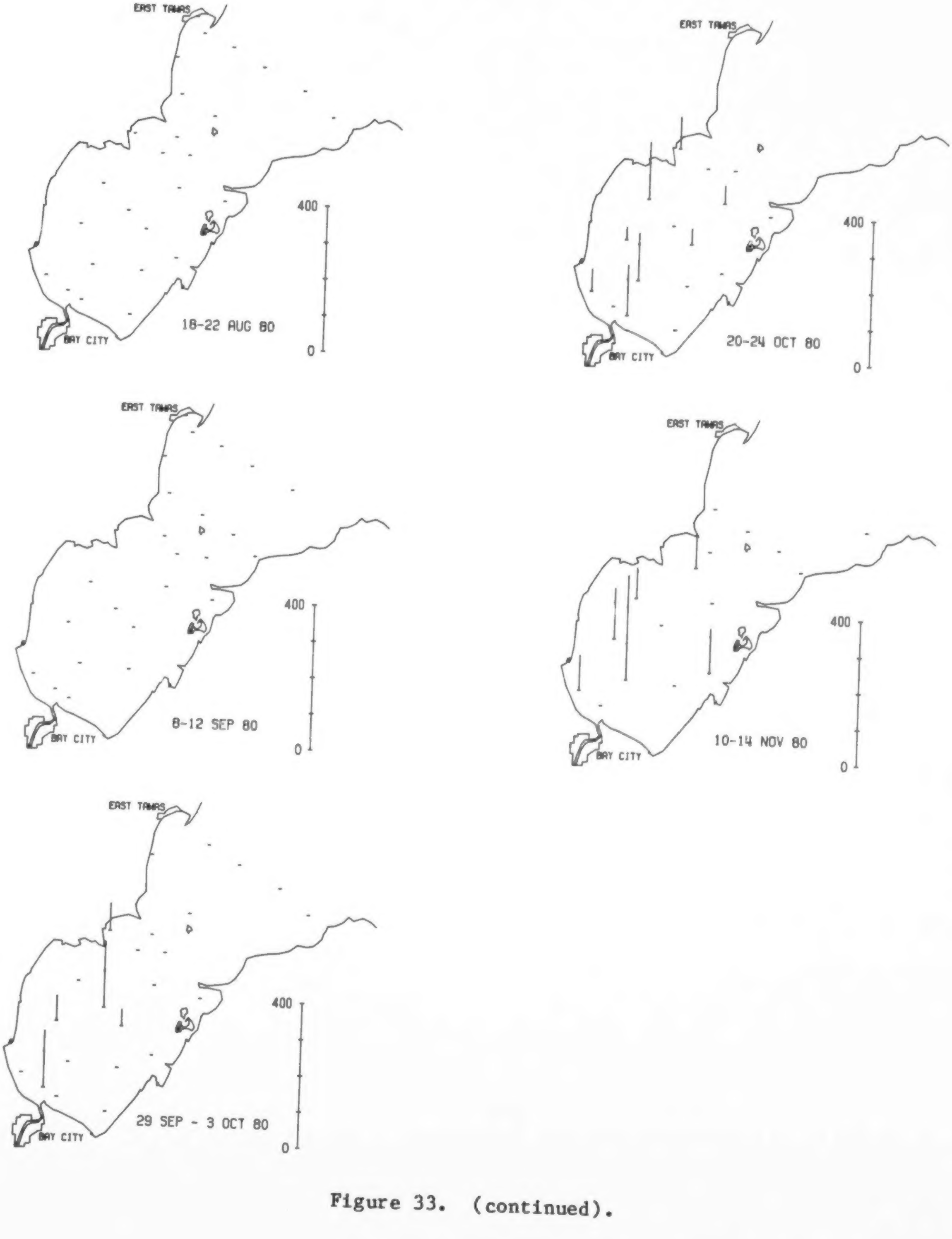

EAST TAWAS
BAY CITY
400
0
18-22 AUG 80
20-24 OCT 80
8-12 SEP 80
10-14 NOV 80
29 SEP - 3 OCT 80

Figure 33. (continued).

Lake Erie. In Saginaw Bay, it reached its maximum abundance in early May at stations near Charity Island and near the Quaniccassee River. Afterwards, it occurred only sporadically and in low numbers until September when a small pulse developed in the inner Bay. It persisted in moderate numbers at these stations through November.

Stephanodiscus hantzschii (Figure 34)

This species is a common element of phytoplankton assemblages in mesotrophic to eutrophic lakes. In April and May it was present in moderate abundance at nearly all of the stations between Charity Island and the Saginaw River. In June, however, its distribution was mainly limited to stations in and near the Saginaw River. Numbers declined through the summer and early fall. By late fall, cell densities had again increased to detectable levels in the inner Bay, primarily at nearshore stations on the east side and near the Saginaw River.

Stephanodiscus subtilis (Figure 35)

In the Great Lakes, this species is associated with eutrophied areas, particularly harbors and bays. Stoermer and Kreis (1980) believed that nearshore populations in Lake Huron were derived from rivers. This species was persistent in the Saginaw River throughout the entire year. Cell densities are high through the spring but decline in August and September. From late September through November, abundance levels and areal distribution for this species are at their greatest, as significant populations occur in and near the Saginaw River and at nearshore stations on both sides of the inner Bay.

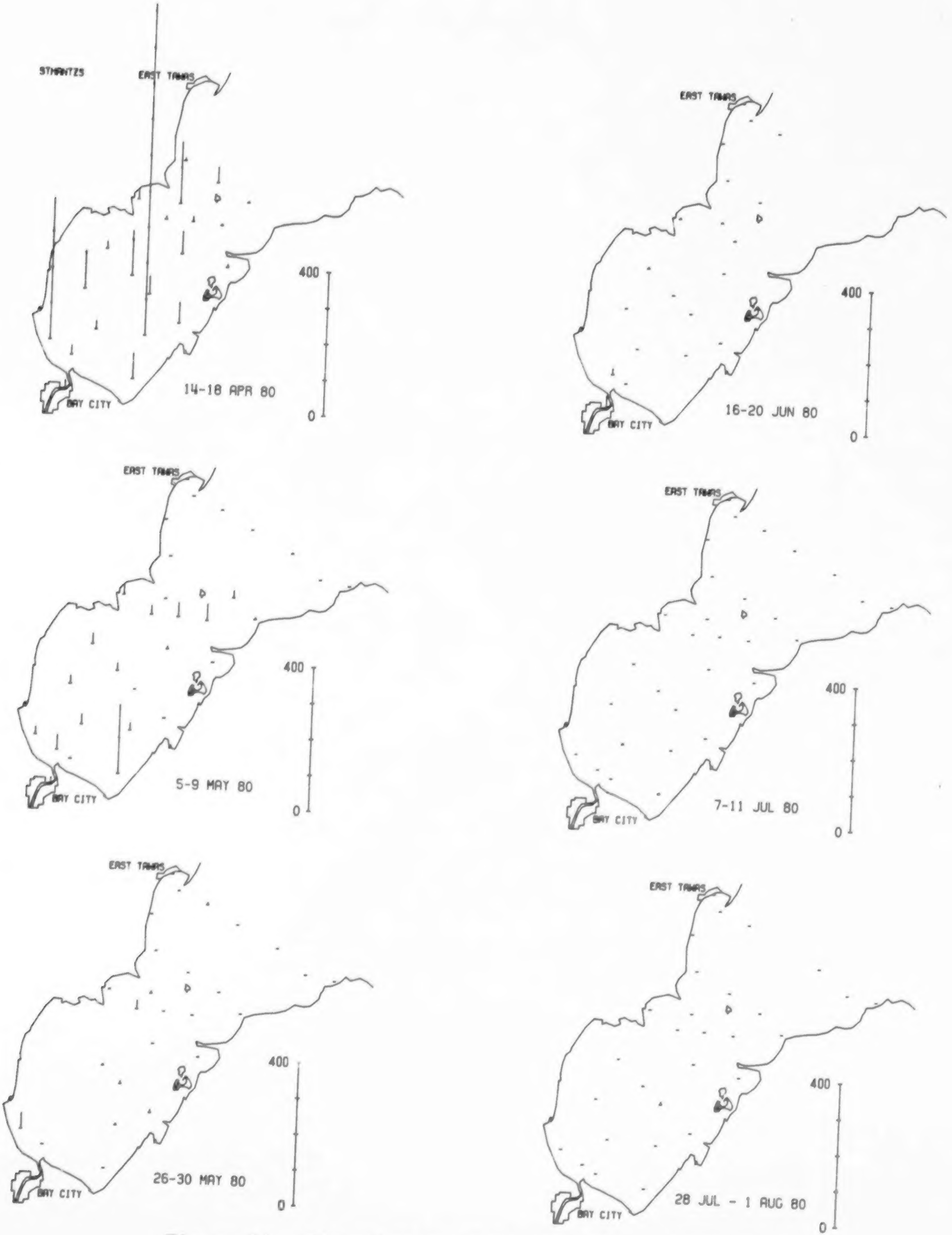

STHANTZS
EAST TAWAS
BAY CITY
14-18 APR 80
400
0
EAST TAWAS
BAY CITY
16-20 JUN 80
400
0
EAST TAWAS
BAY CITY
5-9 MAY 80
400
0
EAST TAWAS
BAY CITY
7-11 JUL 80
400
0
EAST TAWAS
BAY CITY
26-30 MAY 80
400
0
EAST TAWAS
BAY CITY
28 JUL - 1 AUG 80
400
0

Figure 34. Distribution of Stephanodiscus hantzschii.

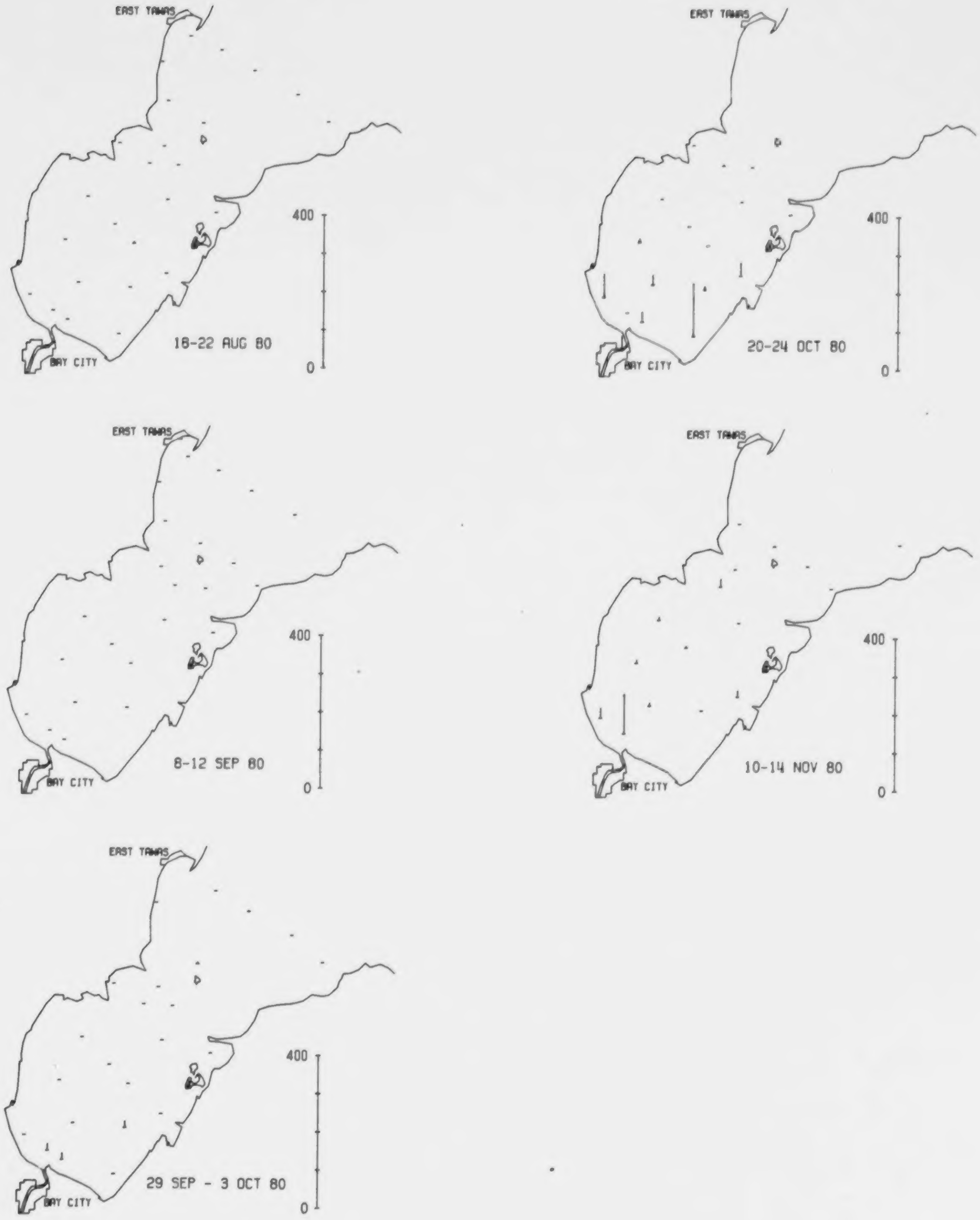

EAST TAWAS
BAY CITY
400
0
18-22 AUG 80
EAST TAWAS
BAY CITY
400
0
20-24 OCT 80
EAST TAWAS
BAY CITY
400
0
8-12 SEP 80
EAST TAWAS
BAY CITY
400
0
10-14 NOV 80
EAST TAWAS
BAY CITY
400
0
29 SEP - 3 OCT 80

Figure 34. (continued).

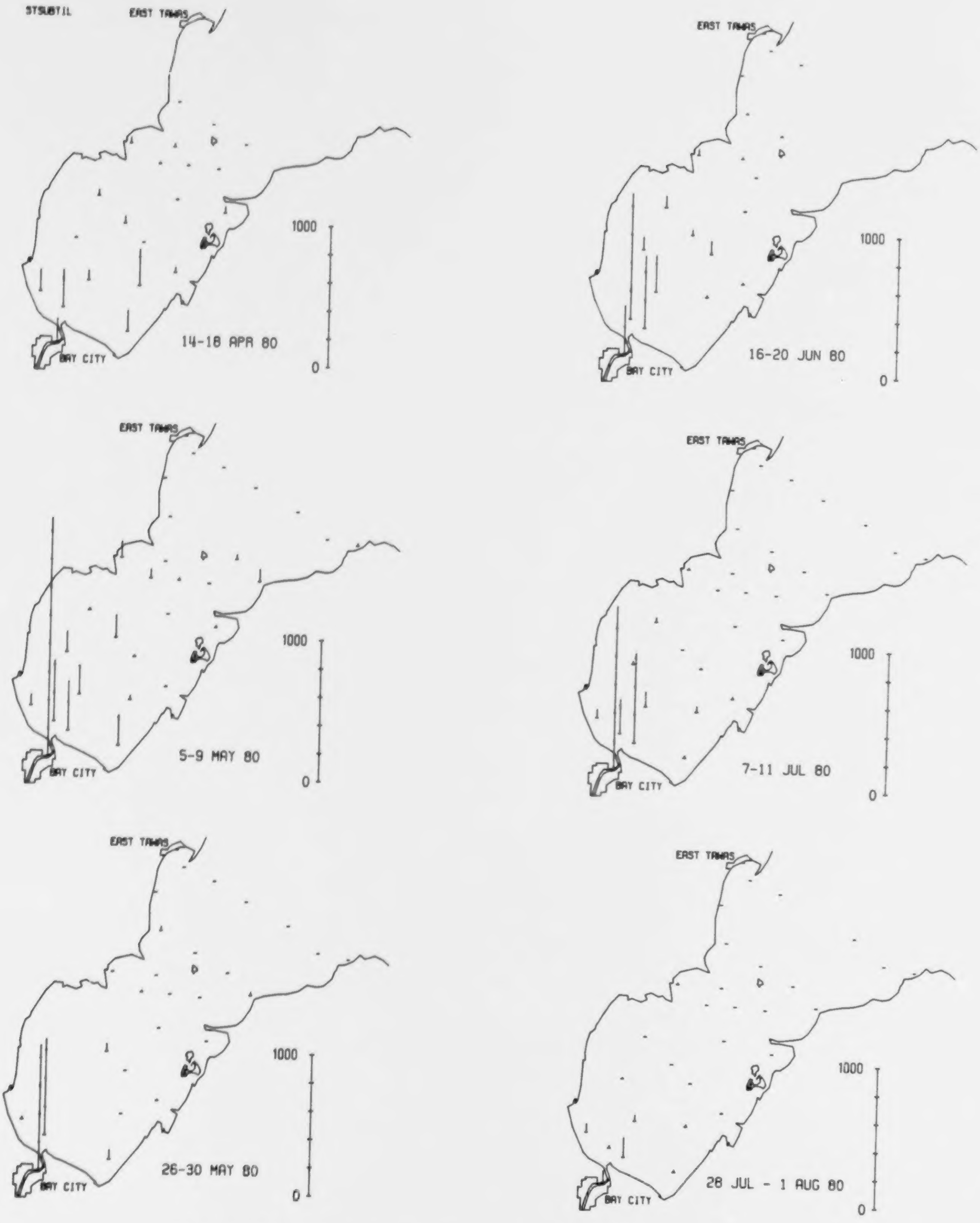

STSUBTIL
EAST TAWAS
BAY CITY
14-18 APR 80
1000
0
EAST TAWAS
BAY CITY
16-20 JUN 80
1000
0
EAST TAWAS
BAY CITY
5-9 MAY 80
1000
0
EAST TAWAS
BAY CITY
7-11 JUL 80
1000
0
EAST TAWAS
BAY CITY
26-30 MAY 80
1000
0
EAST TAWAS
BAY CITY
28 JUL - 1 AUG 80
1000
0

Figure 35. Distribution of Stephanodiscus subtilis.

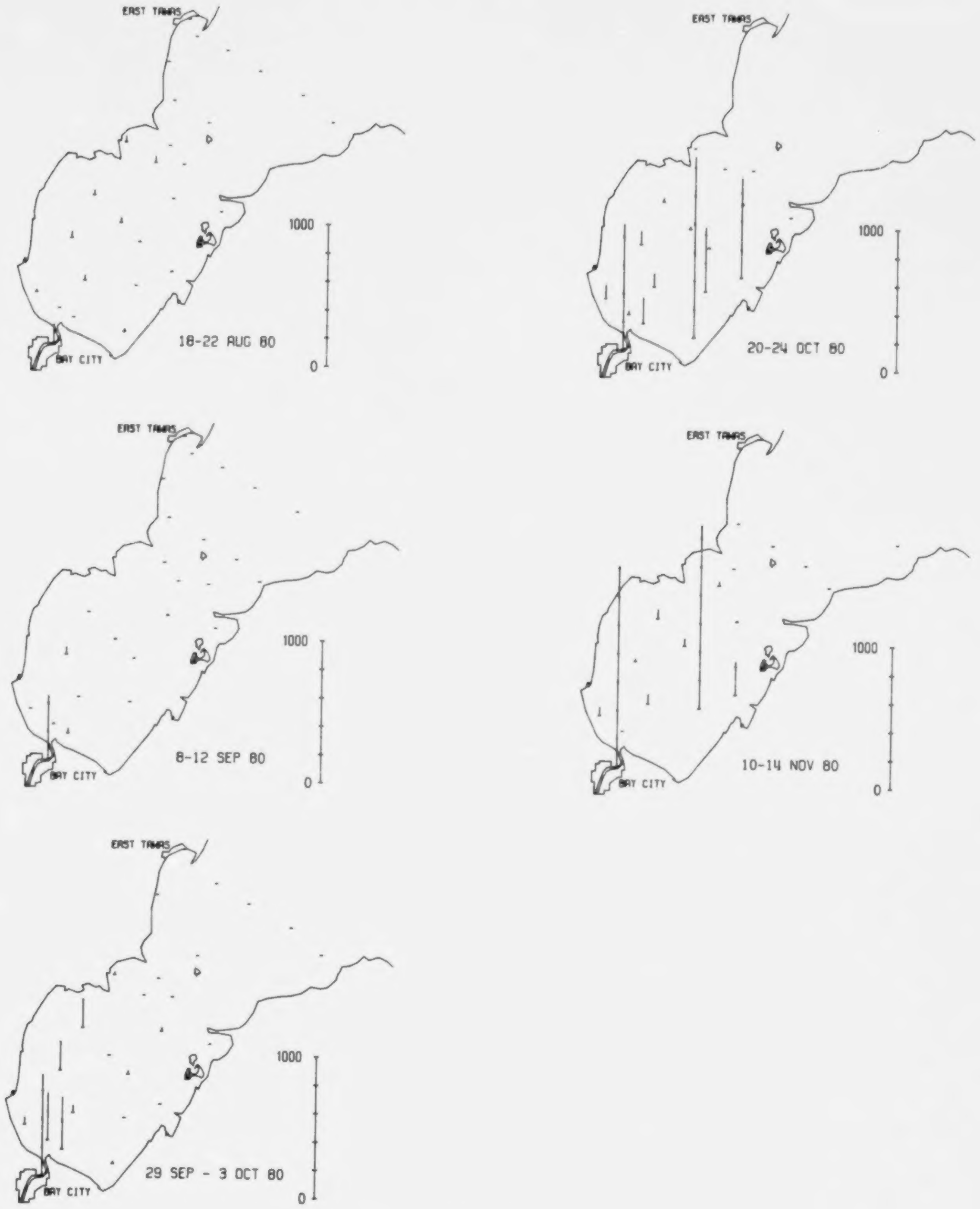

EAST TAWAS
BAY CITY
1000
0
18-22 AUG 80
20-24 OCT 80
8-12 SEP 80
10-14 NOV 80
29 SEP - 3 OCT 80

Figure 35. (continued).

Stephanodiscus tenuis (Figure 36)

This taxon is abundant in rivers throughout North America and in the Great Lakes it is characteristic of mesotrophic to eutrophic areas. In Saginaw Bay populations are strongly associated with the Saginaw River, and the two stations (7 and 8) near the river mouth. In May, it reaches its greatest distribution, occurring in abundance at several stations in the inner Bay and sporadically and in low abundance near Charity Island. It persists in the river, although in low abundance throughout the year. In late fall, populations again develop in the river and at stations in the extreme southeastern portion of the Bay.

Synedra filiformis (Figure 37)

This species is common in the upper Great Lakes in the spring and is apparently tolerant of a wide variety of environmental conditions. In Saginaw Bay, it is distributed over all stations in April and May. Although numbers are somewhat reduced at stations at the Bay-Lake Huron interface, it is relatively abundant in these oligotrophic waters. From May to early July, it is largely absent from the Bay, but a large population develops in Wild Fowl Bay in late July and persists through October. Sporadic occurrences of low population levels are found in August and September at most middle Bay stations. During August, moderate densities develop in the extreme southeastern portion of the Bay. This species was unique among diatoms in its persistent, numerically important contribution to Wild Fowl Bay.

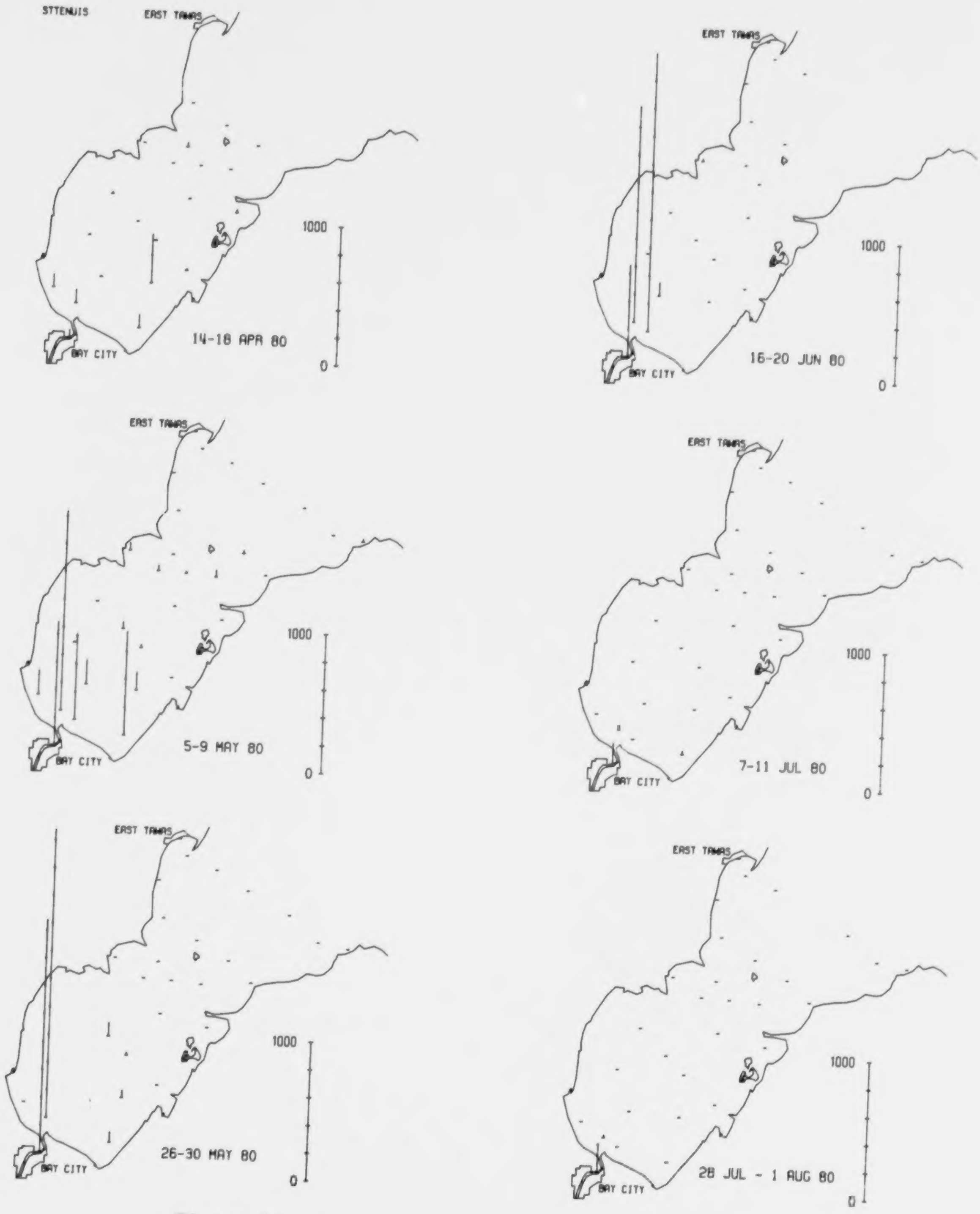

STTENUIS
EAST TAWAS
BAY CITY
14-18 APR 80
1000
0
EAST TAWAS
BAY CITY
16-20 JUN 80
1000
0
EAST TAWAS
BAY CITY
5-9 MAY 80
1000
0
EAST TAWAS
BAY CITY
7-11 JUL 80
1000
0
EAST TAWAS
BAY CITY
26-30 MAY 80
1000
0
EAST TAWAS
BAY CITY
28 JUL - 1 AUG 80
1000
0

Figure 36. Distribution of Stephanodiscus tenuis.

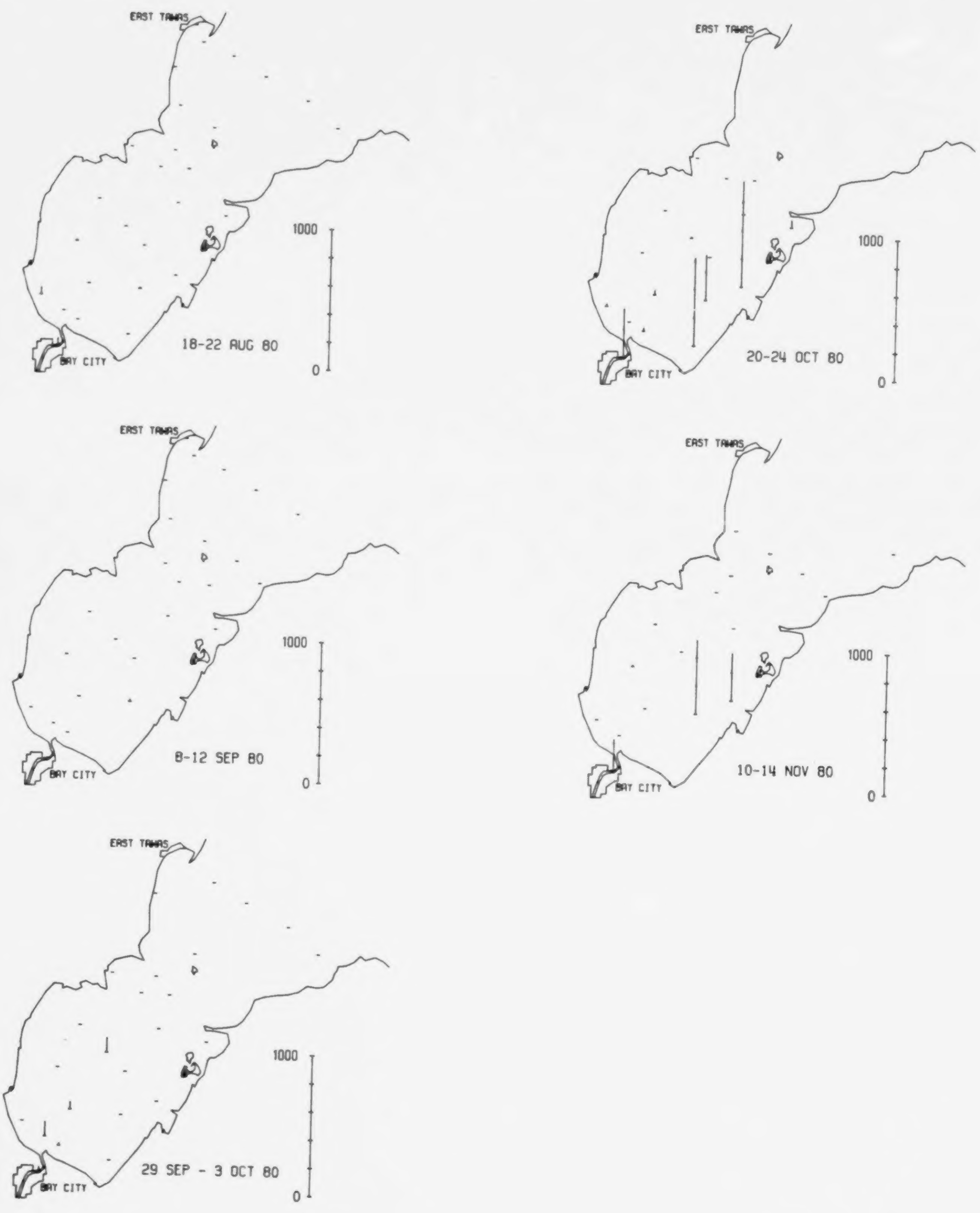

EAST TAWAS
BAY CITY
18-22 AUG 80
1000
0
EAST TAWAS
BAY CITY
20-24 OCT 80
1000
0
EAST TAWAS
BAY CITY
8-12 SEP 80
1000
0
EAST TAWAS
BAY CITY
10-14 NOV 80
1000
0
EAST TAWAS
BAY CITY
29 SEP - 3 OCT 80
1000
0

Figure 36. (continued).

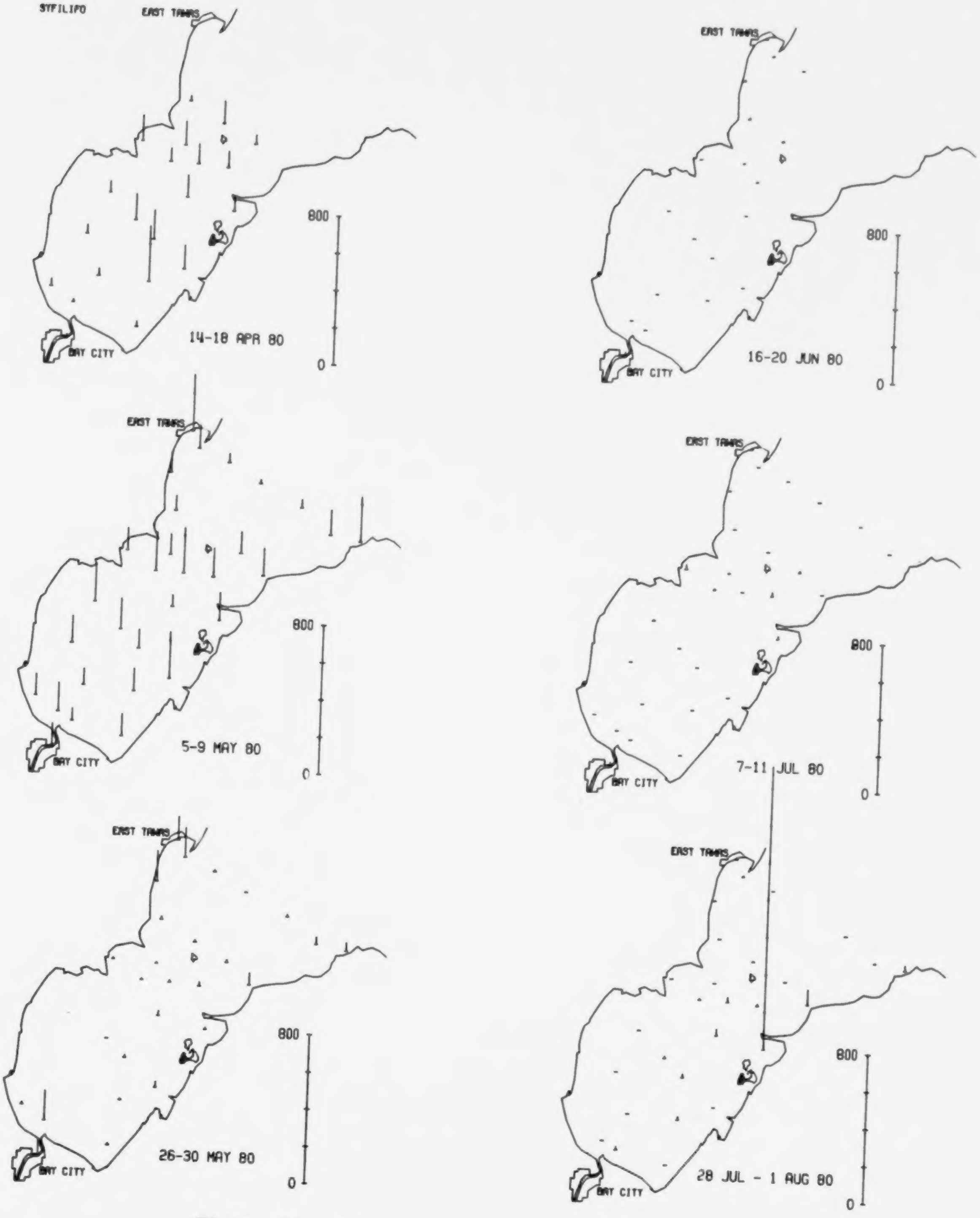

SYFILIFO
EAST TAWAS
BAY CITY
14-18 APR 80
800
0
EAST TAWAS
BAY CITY
16-20 JUN 80
800
0
EAST TAWAS
BAY CITY
5-9 MAY 80
800
0
EAST TAWAS
BAY CITY
7-11 JUL 80
800
0
EAST TAWAS
BAY CITY
26-30 MAY 80
800
0
EAST TAWAS
BAY CITY
28 JUL - 1 AUG 80
800
0

Figure 37. Distribution of Synedra filiformis.

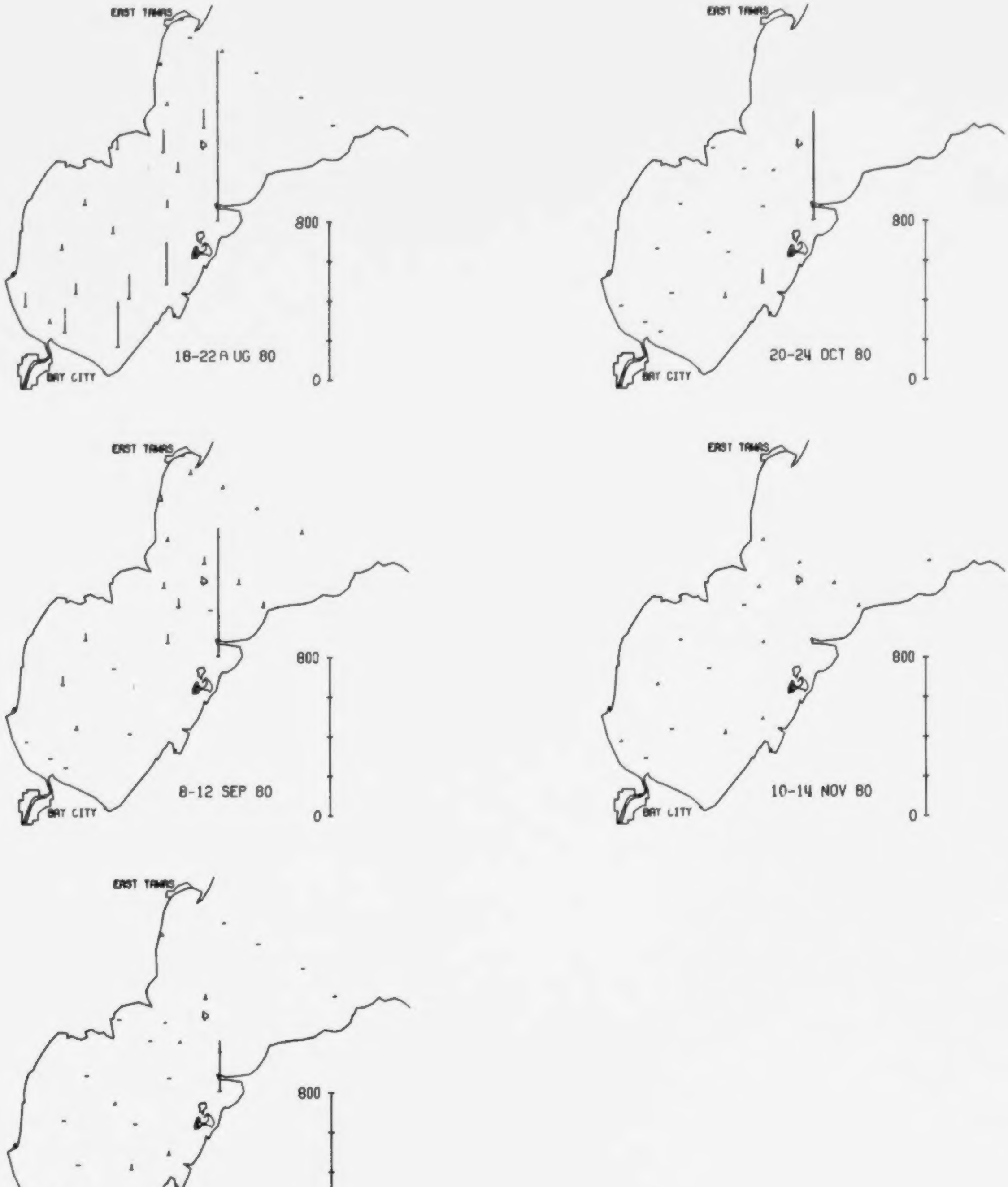

EAST TAWAS
BAY CITY
800
0
18-22 AUG 80
20-24 OCT 80
8-12 SEP 80
10-14 NOV 80
29 SEP - 3 OCT 80

Figure 37. (continued).

Thalassiosira sp. (Figure 38)

Specific identification of this taxon could not be confidently made because of its small size and its weakly silicified valves. Most representatives of this genus are marine and species with a freshwater distribution are generally limited to rivers and to regions of high conductivity. This entity reached its maximum abundance in the Saginaw River, occurring in the Bay only sporadically and in low cell densities at stations near the river mouth.

Chlorophyta or Green Algae (Figure 39)

The green algal flora is more diverse and abundant in Saginaw Bay than in most areas of the upper Great Lakes. Green algae numbers increase in the inner Bay from May through August. Cell densities during this period are greatest in the eastern portion of the inner bay, somewhat lower in the eastern middle Bay, and very low in the extreme western and middle Bay. In September, maximum abundances are found at eastern stations of the inner Bay, especially Wild Fowl Bay and Oak Point. Cell densities decline through November; moderate levels are persistent in the extreme southeastern area and in the Saginaw River.

Chodatella quadriseta (Figure 40)

This species is a common element of phytoplankton assemblages in mesotrophic to eutrophic lakes. In the Laurentian Great Lakes, it is usually found in significant abundance only in eutrophic areas. Initial development of populations of this species took place on the eastern side of the Bay in early July. The maximum was reached in early August, and from late September to November the species occurred only sporadically.

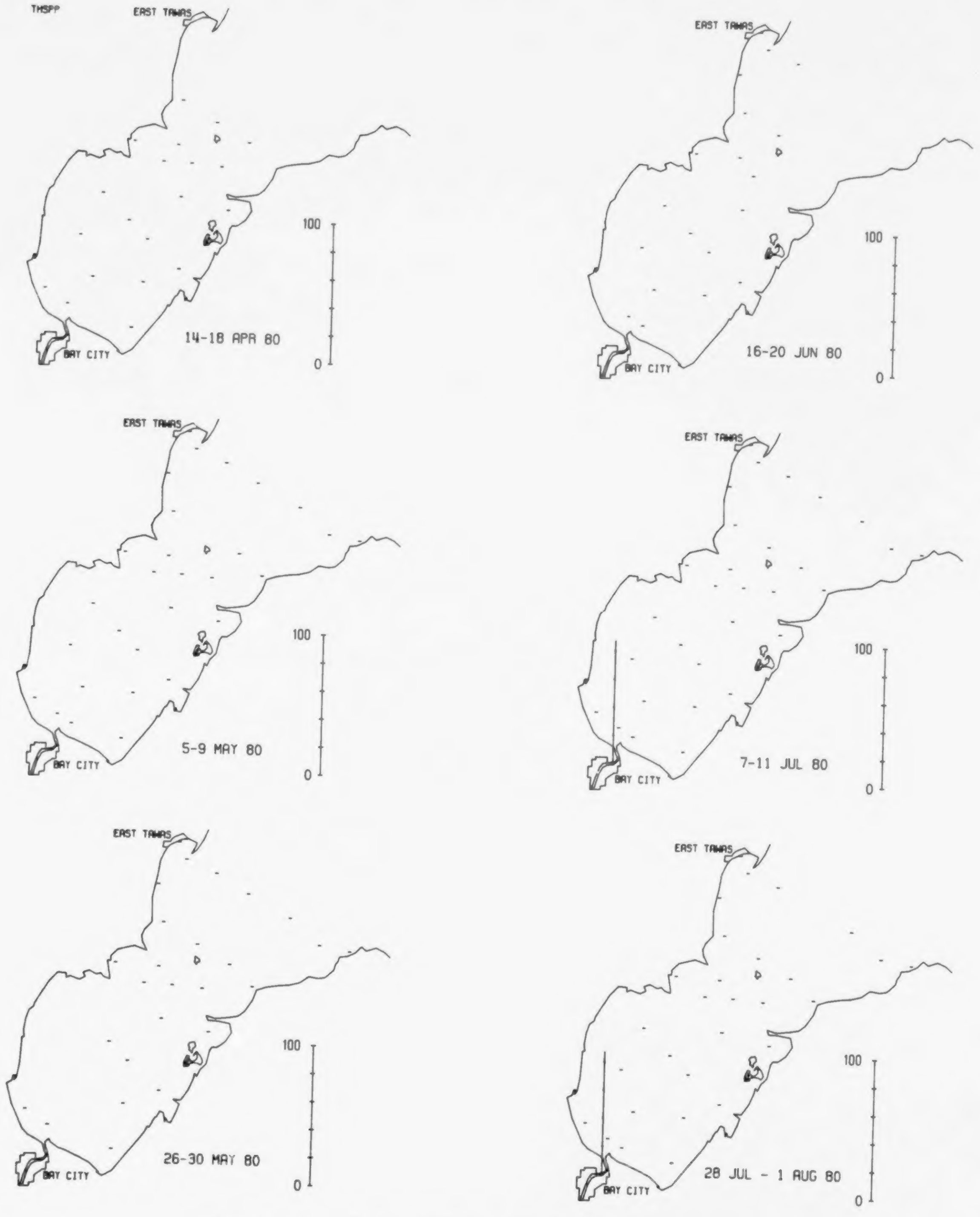

THSPP
EAST TAWAS
100
0
BAY CITY
14-18 APR 80
EAST TAWAS
100
0
BAY CITY
16-20 JUN 80
EAST TAWAS
100
0
BAY CITY
5-9 MAY 80
EAST TAWAS
100
0
BAY CITY
7-11 JUL 80
EAST TAWAS
100
0
BAY CITY
26-30 MAY 80
EAST TAWAS
100
0
BAY CITY
28 JUL - 1 AUG 80

Figure 38. Distribution of Thalassiosira spp.

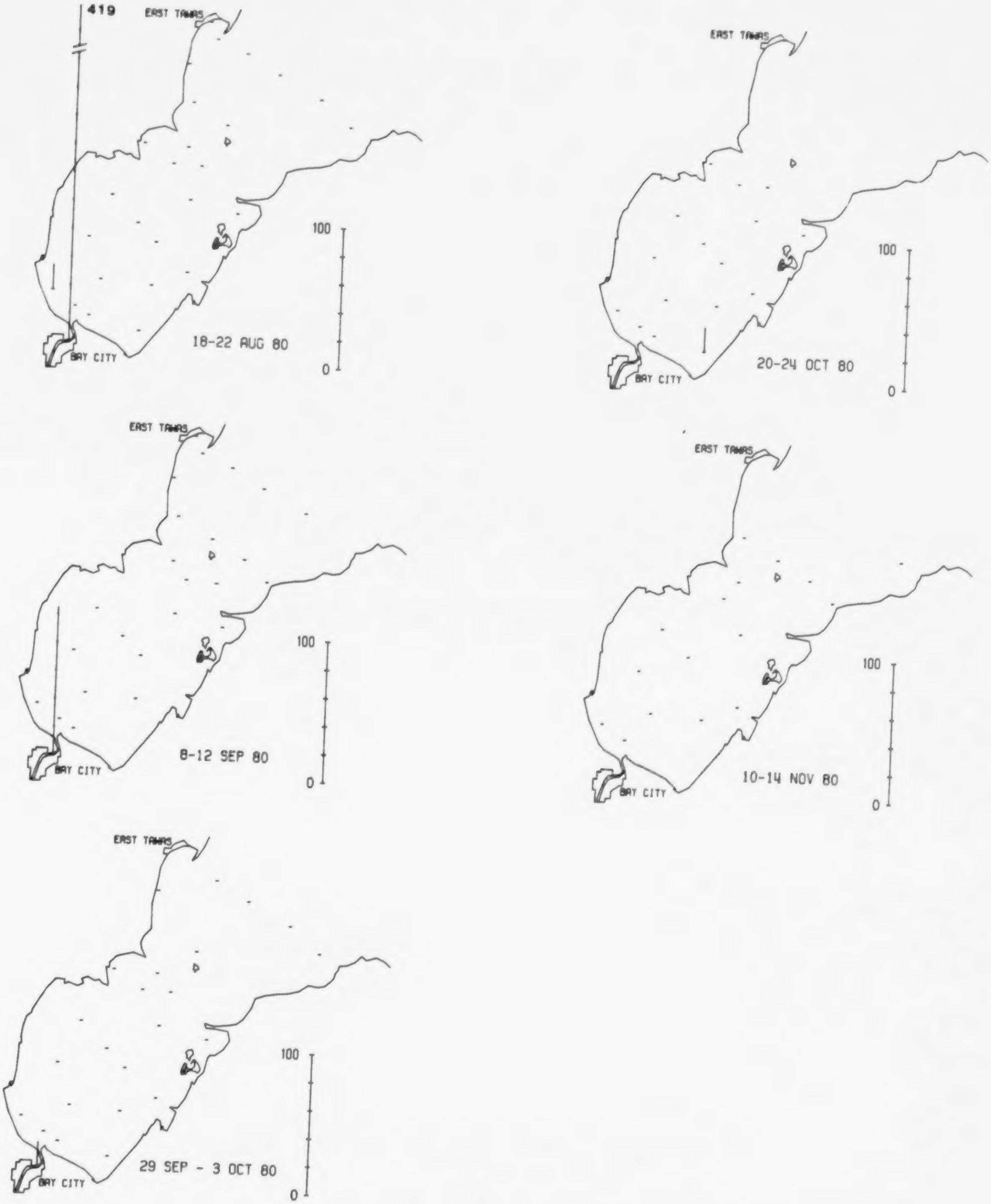

419
EAST TAWAS
BAY CITY
18-22 AUG 80
100
0
EAST TAWAS
BAY CITY
20-24 OCT 80
100
0
EAST TAWAS
BAY CITY
8-12 SEP 80
100
0
EAST TAWAS
BAY CITY
10-14 NOV 80
100
0
EAST TAWAS
BAY CITY
29 SEP - 3 OCT 80
100
0

Figure 38. (continued).

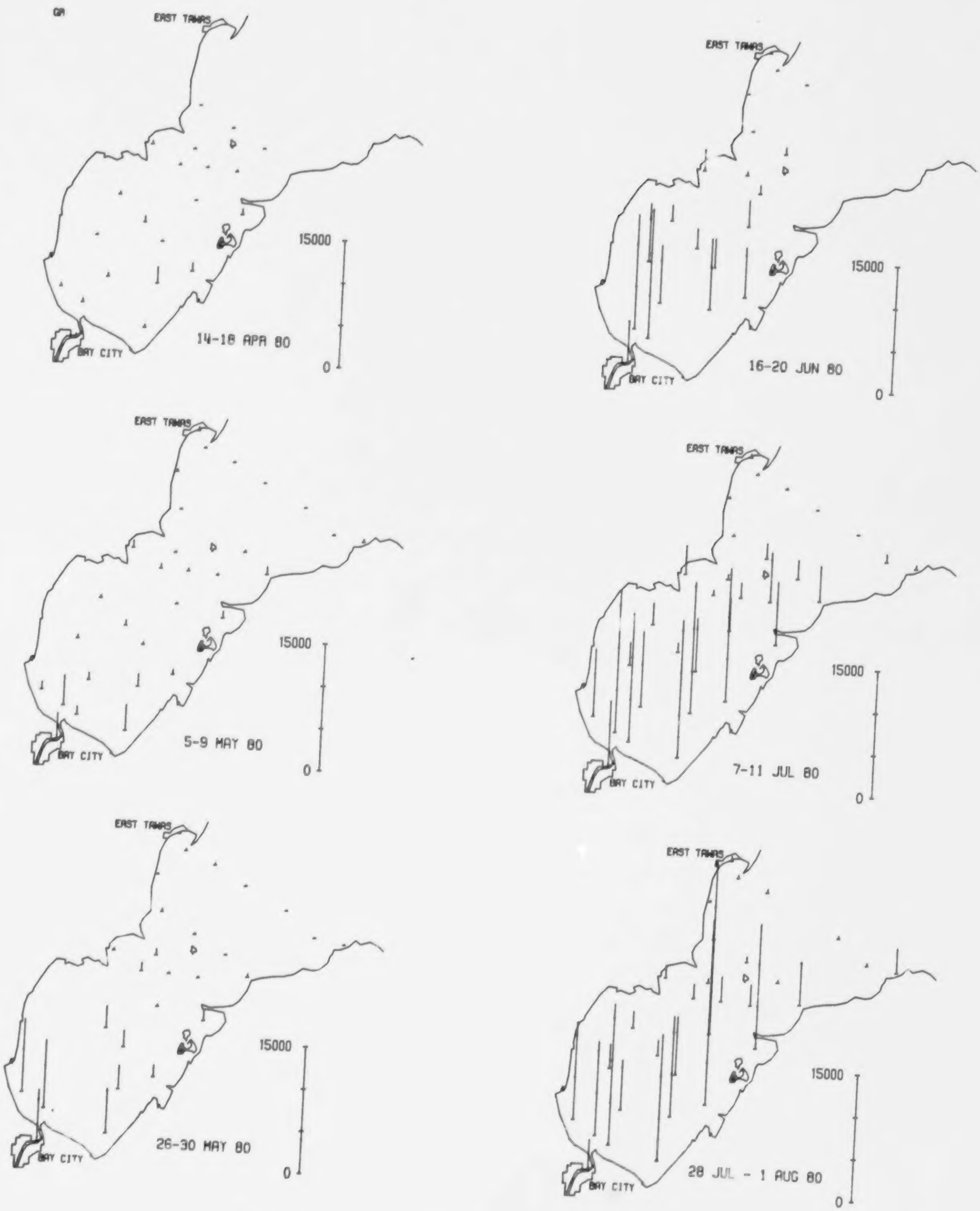

GR
EAST TAWAS
BAY CITY
15000
0
14-18 APR 80
16-20 JUN 80
5-9 MAY 80
7-11 JUL 80
26-30 MAY 80
28 JUL - 1 AUG 80

Figure 39. Distribution of green algae.

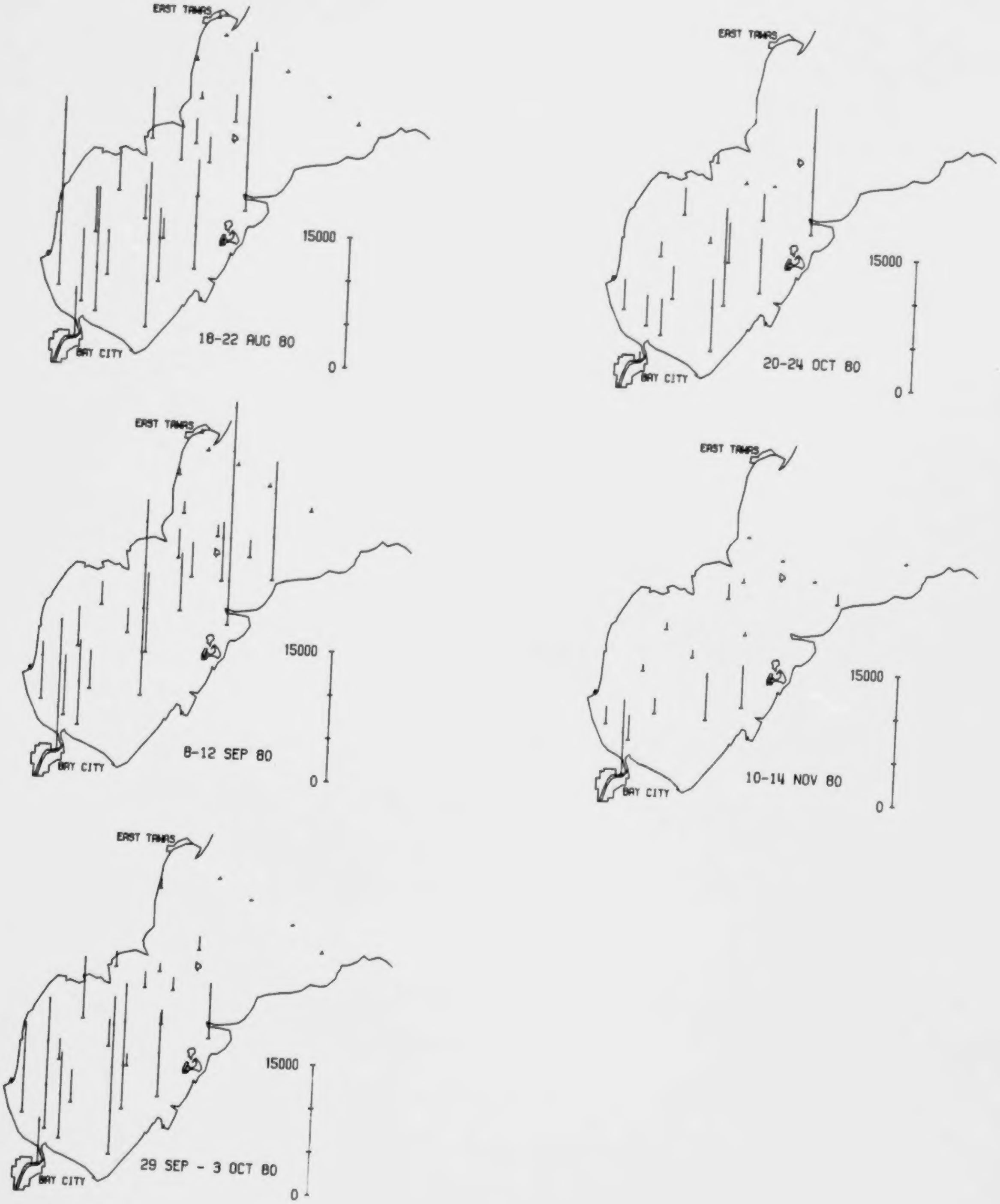

EAST TAWAS
BAY CITY
15000
0
18-22 AUG 80
20-24 OCT 80
8-12 SEP 80
10-14 NOV 80
29 SEP - 3 OCT 80

Figure 39. (continued).

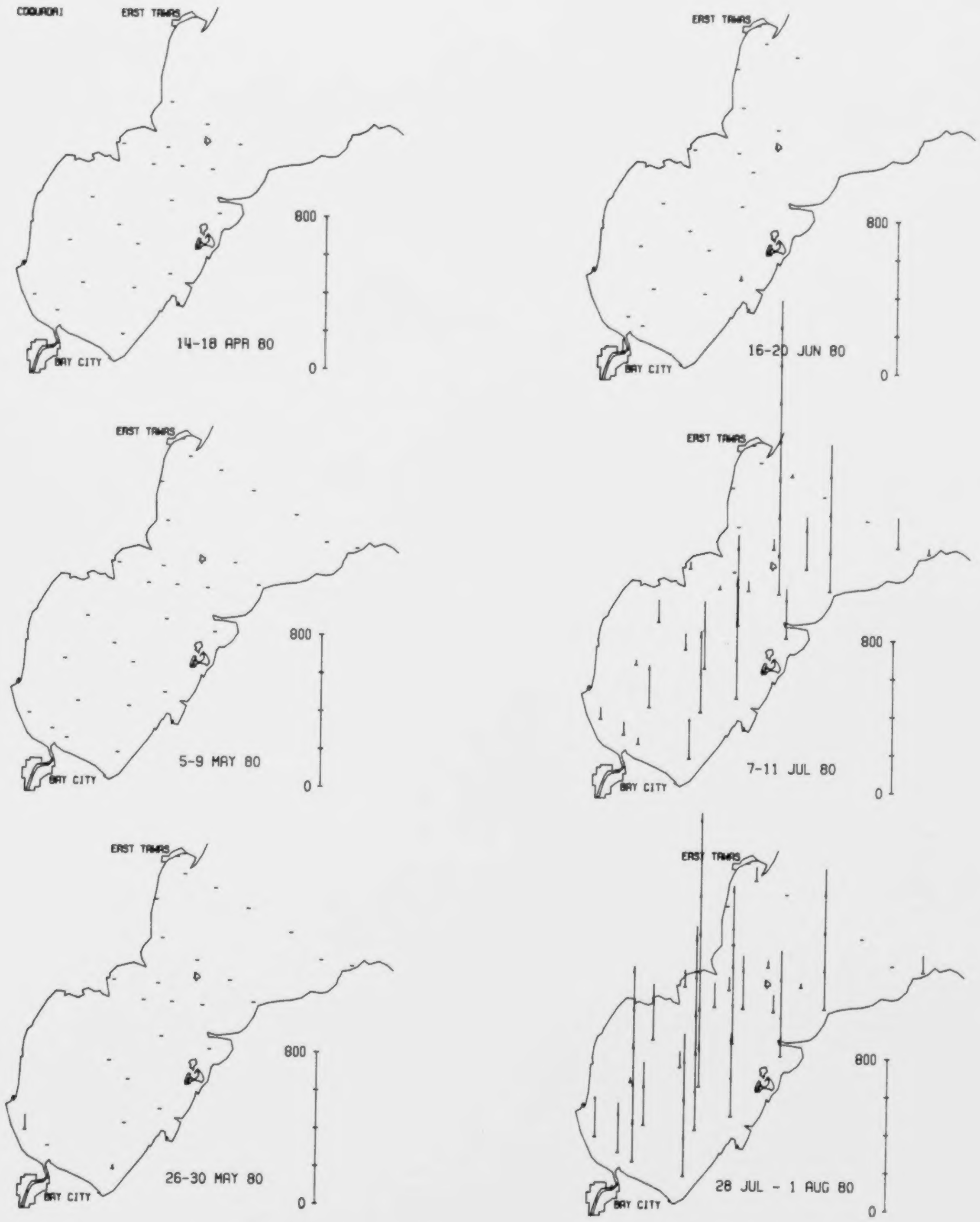

COQUADRI
EAST TAWAS
BAY CITY
14-18 APR 80
5-9 MAY 80
26-30 MAY 80
16-20 JUN 80
7-11 JUL 80
28 JUL - 1 AUG 80
800
0

Figure 40. Distribution of Chodatella quadriseta.

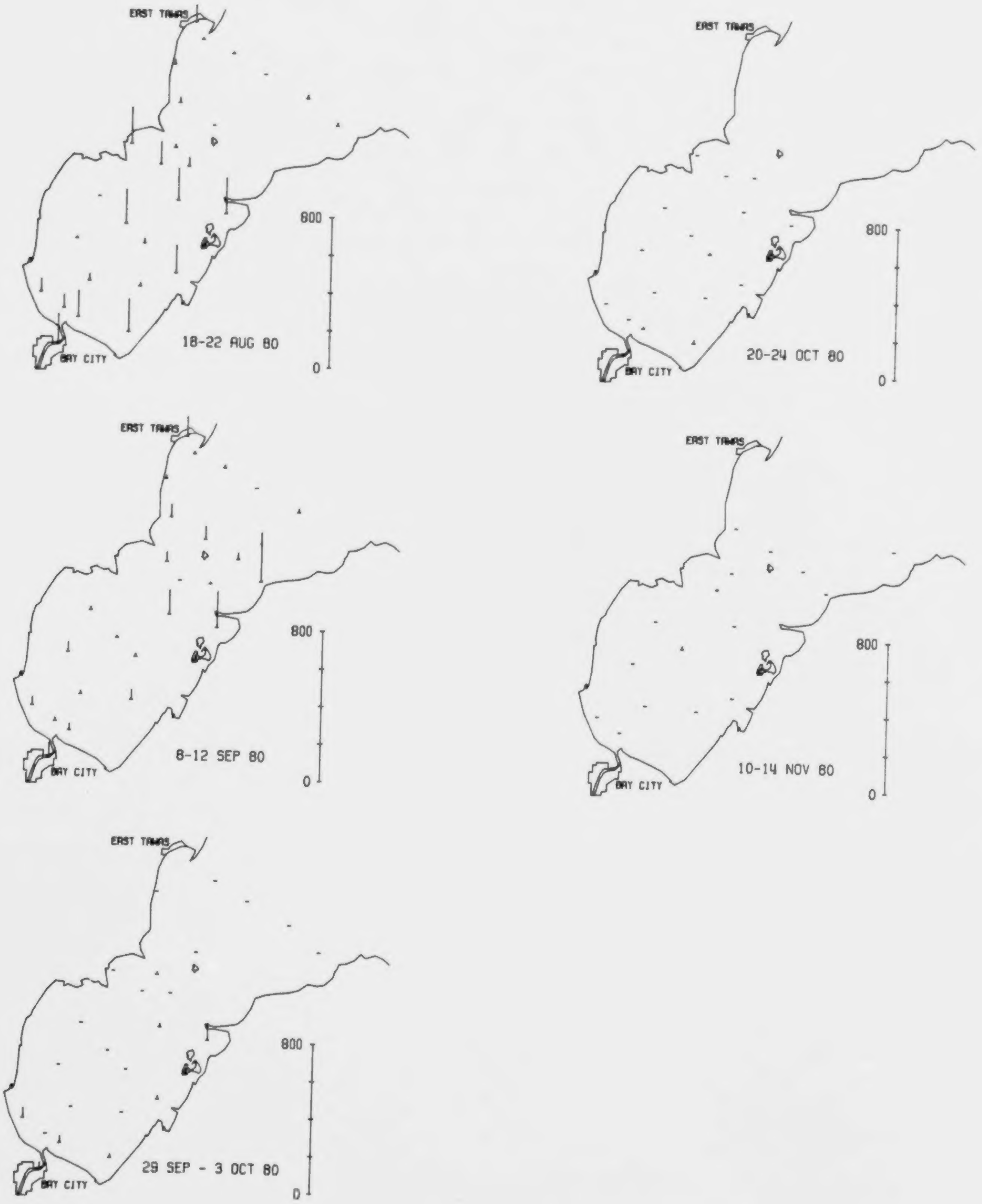

EAST TAWAS
BAY CITY
18-22 AUG 80
800
0
EAST TAWAS
BAY CITY
20-24 OCT 80
800
0
EAST TAWAS
BAY CITY
8-12 SEP 80
800
0
EAST TAWAS
BAY CITY
10-14 NOV 80
800
0
EAST TAWAS
BAY CITY
29 SEP - 3 OCT 80
800
0

Figure 40. (continued).

Coelastrum microporum (Figure 41)

This species was present in low abundance in the first two cruises. Population development began in May in the inner Bay. Cell density increased through June and July as the species spread through the inner Bay. After early August, abundance decreased, although the species persisted through November. Maximum abundance was reached in the southeastern corner of the Bay and at the river mouth stations. This species is common in mesotrophic to eutrophic areas of the Great Lakes.

Gloeotila pelagica (Figure 42)

Very large populations of this green filament developed in August but at only a few stations. Maximum abundance was reached in early September in Wild Fowl Bay where it was dominant. Its distribution also reached a maximum in early September, but this species remained limited to nearshore areas along the east side of the Bay and near the river mouth.

Mougeotia sp. (Figure 43)

We have been unable to make a satisfactory specific identification of this entity due to the lack of sexually mature material. It occurred sporadically in low abundance in the inner Bay until July when a large population developed in the eastern Bay. Cell densities then declined slowly throughout the rest of the year. As its numerical abundance decreased, its distribution increased, and from August through October, it was found in low levels from the shallows just north of Charity Island, along the east side of the Bay to the stations near the river mouth.

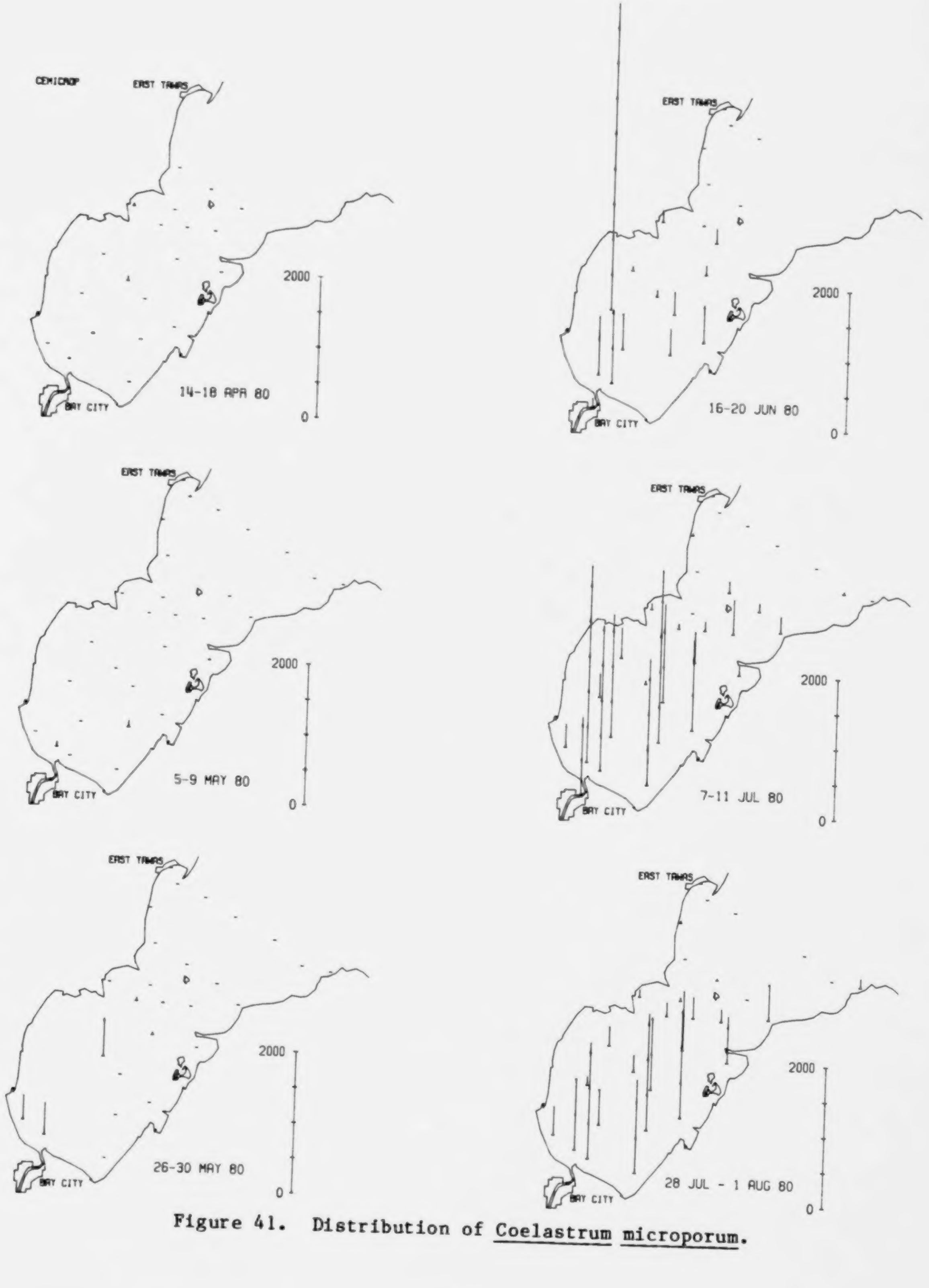

CEMICROP
EAST TAWAS
BAY CITY
14-18 APR 80
2000
0
EAST TAWAS
BAY CITY
16-20 JUN 80
2000
0
EAST TAWAS
BAY CITY
5-9 MAY 80
2000
0
EAST TAWAS
BAY CITY
7-11 JUL 80
2000
0
EAST TAWAS
BAY CITY
26-30 MAY 80
2000
0
EAST TAWAS
BAY CITY
28 JUL - 1 AUG 80
2000
0

Figure 41. Distribution of Coelastrum microporum.

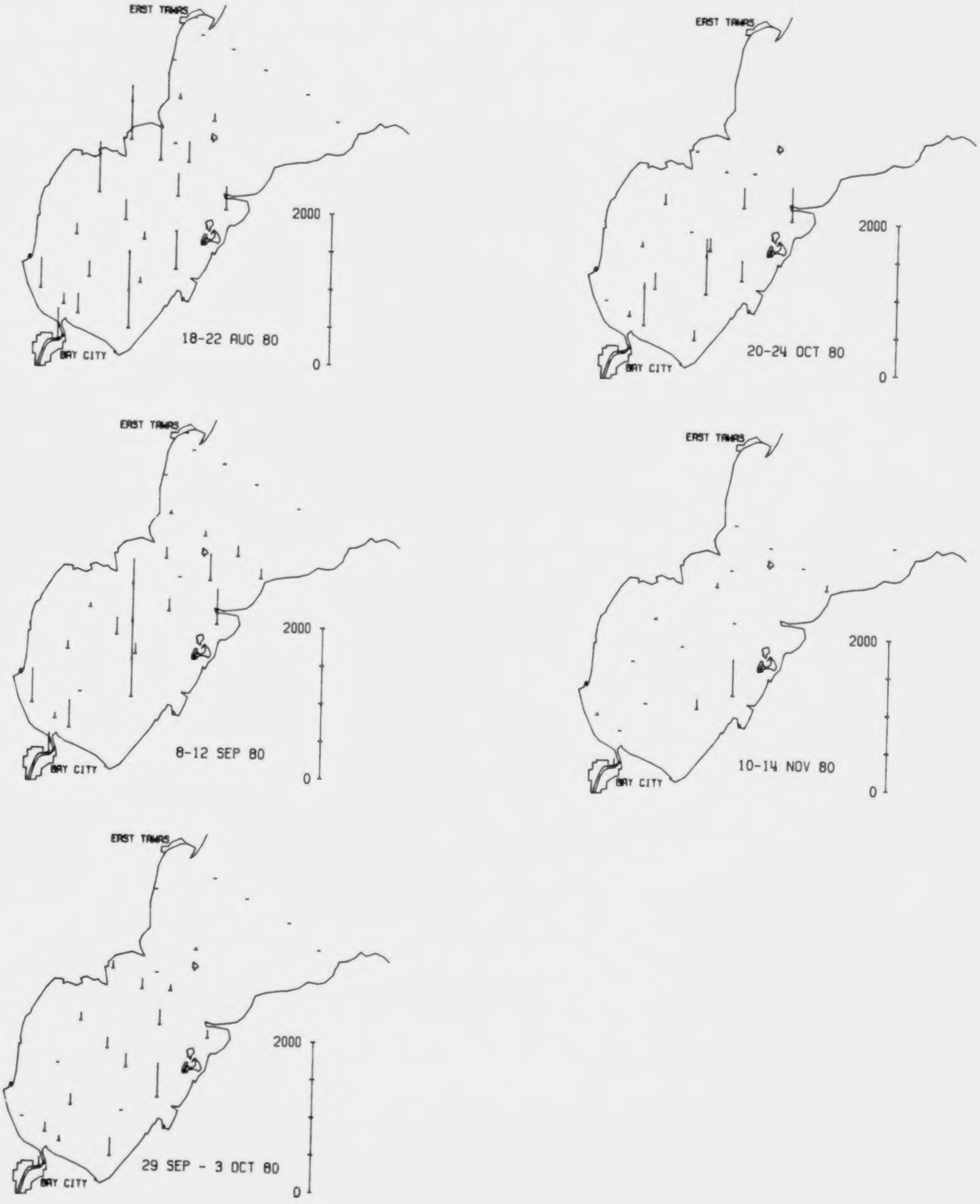

EAST TAWAS
BAY CITY
18-22 AUG 80
2000
0
EAST TAWAS
BAY CITY
20-24 OCT 80
2000
0
EAST TAWAS
BAY CITY
8-12 SEP 80
2000
0
EAST TAWAS
BAY CITY
10-14 NOV 80
2000
0
EAST TAWAS
BAY CITY
29 SEP - 3 OCT 80
2000
0

Figure 41. (continued).

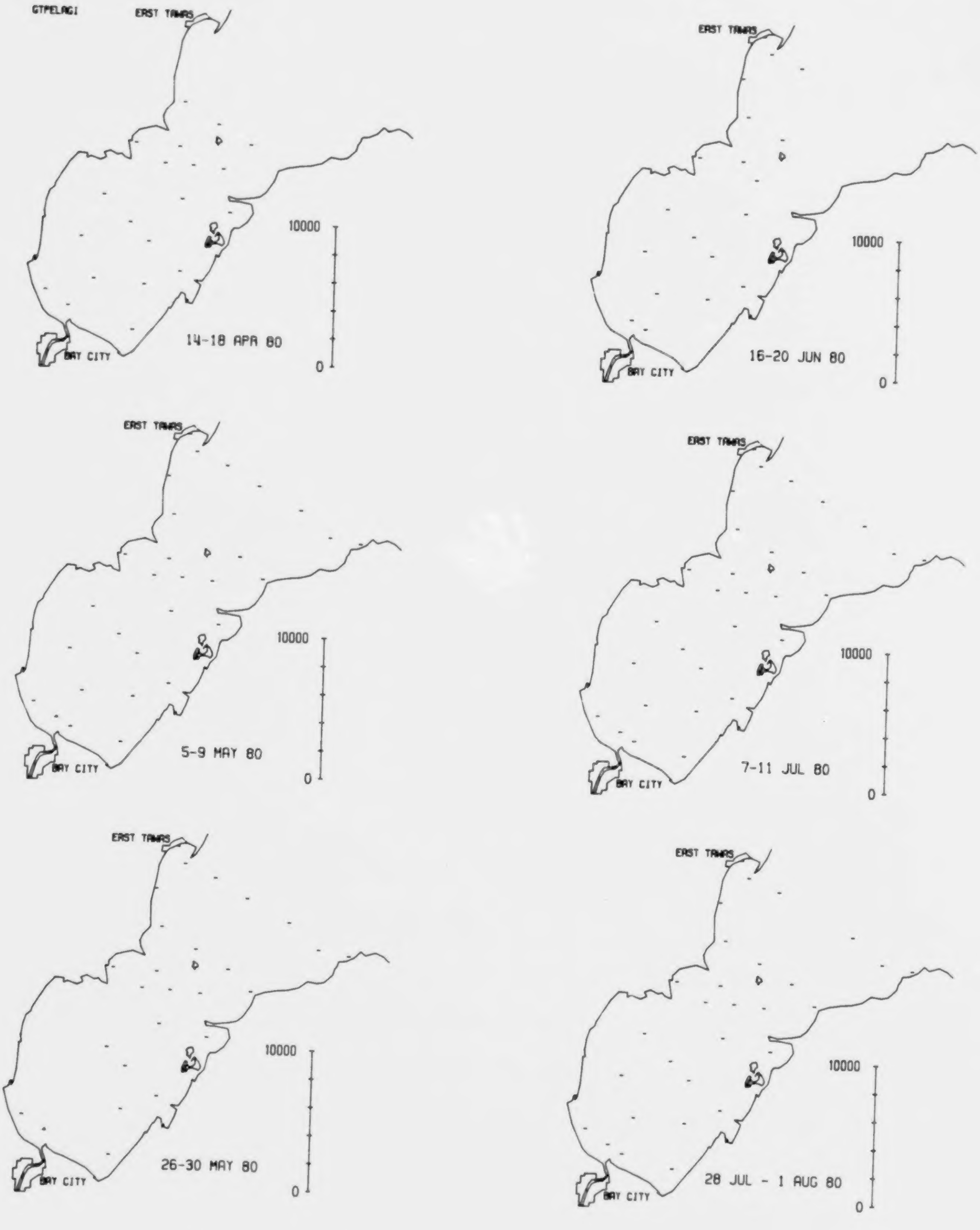

GTPELAGI
EAST TAWAS
BAY CITY
10000
0
14-18 APR 80
EAST TAWAS
BAY CITY
10000
0
16-20 JUN 80
EAST TAWAS
BAY CITY
10000
0
5-9 MAY 80
EAST TAWAS
BAY CITY
10000
0
7-11 JUL 80
EAST TAWAS
BAY CITY
10000
0
26-30 MAY 80
EAST TAWAS
BAY CITY
10000
0
28 JUL - 1 AUG 80

Figure 42. Distribution of Gloeotila pelagica.

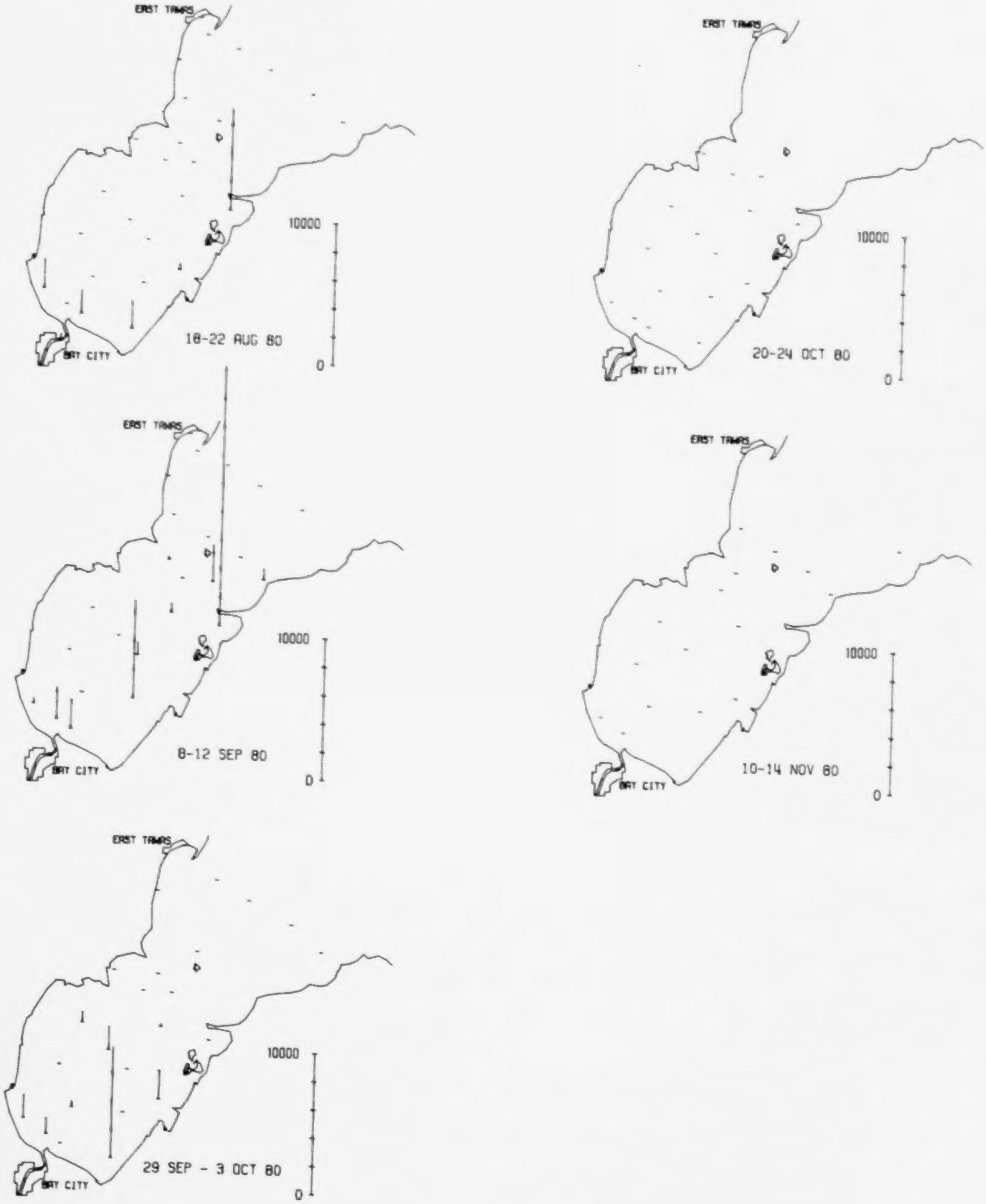

EAST TAWAS
BAY CITY
10000
0
18-22 AUG 80
20-24 OCT 80
8-12 SEP 80
10-14 NOV 80
29 SEP - 3 OCT 80

Figure 42. (continued).

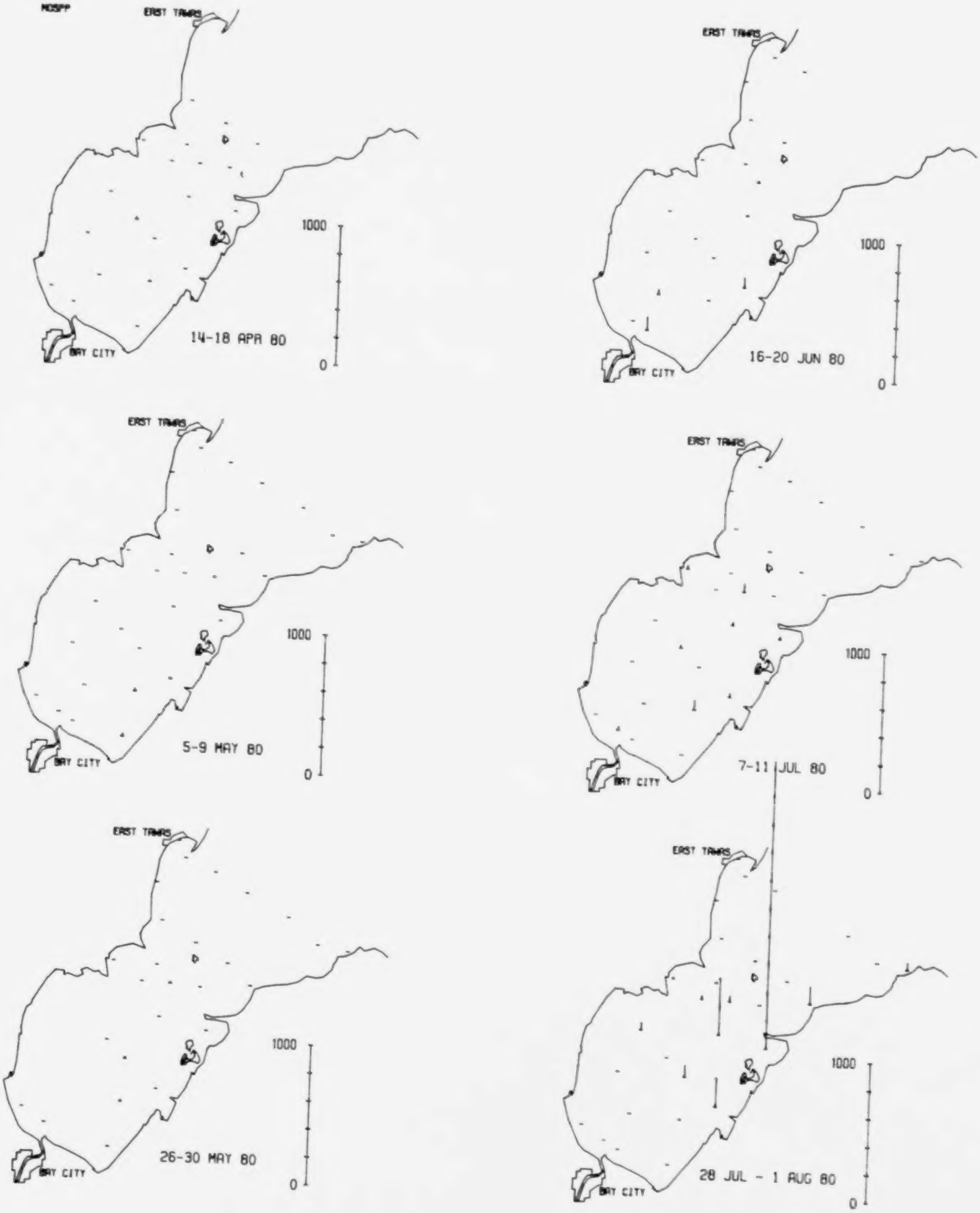

MOSPP
EAST TAWAS
BAY CITY
14-18 APR 80
1000
0
EAST TAWAS
BAY CITY
16-20 JUN 80
1000
0
EAST TAWAS
BAY CITY
5-9 MAY 80
1000
0
EAST TAWAS
BAY CITY
7-11 JUL 80
1000
0
EAST TAWAS
BAY CITY
26-30 MAY 80
1000
0
EAST TAWAS
BAY CITY
28 JUL - 1 AUG 80
1000
0

Figure 43. Distribution of Mougeotia sp.

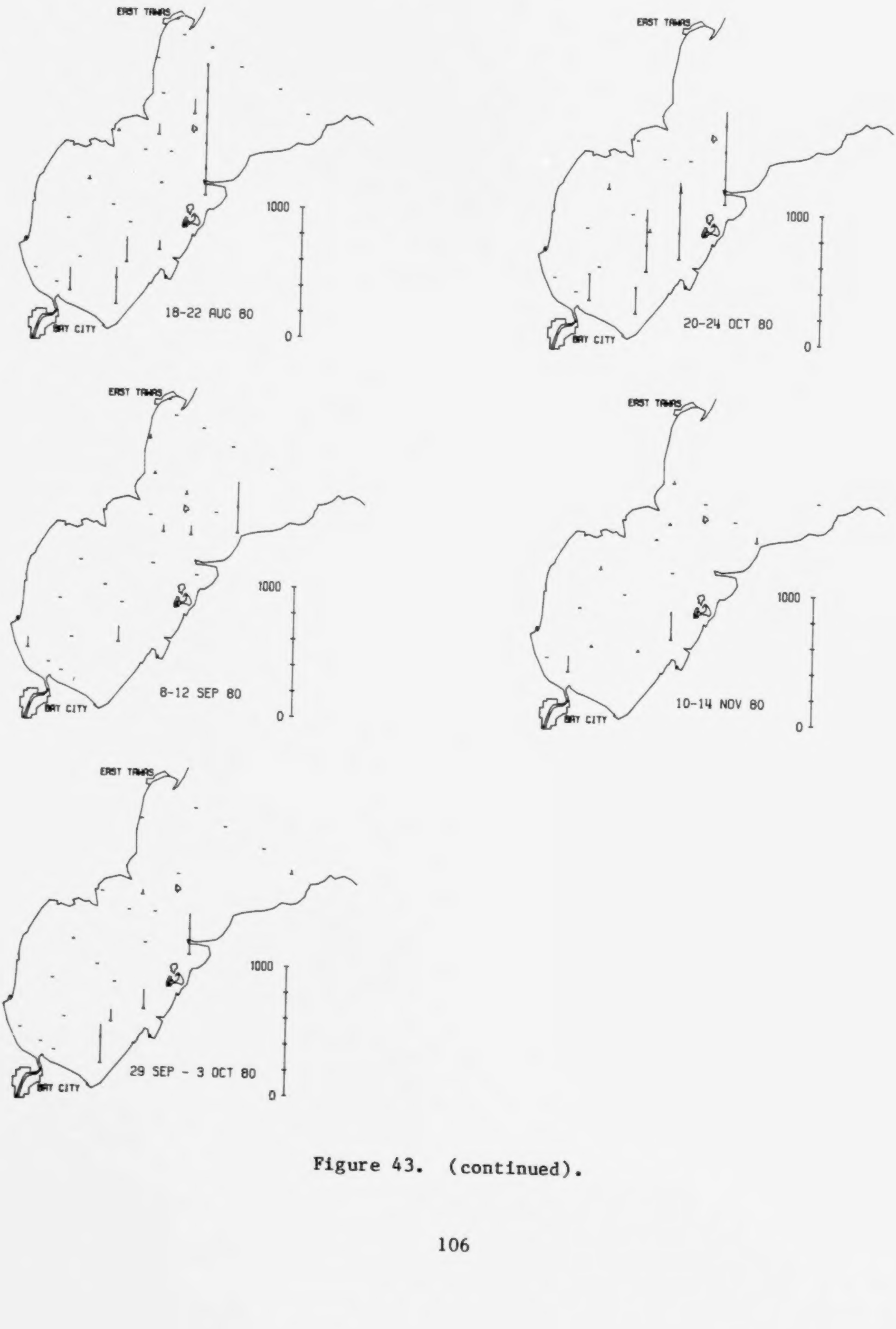

EAST TAWAS
BAY CITY
1000
0
18-22 AUG 80
EAST TAWAS
BAY CITY
1000
0
20-24 OCT 80
EAST TAWAS
BAY CITY
1000
0
8-12 SEP 80
EAST TAWAS
BAY CITY
1000
0
10-14 NOV 80
EAST TAWAS
BAY CITY
1000
0
29 SEP - 3 OCT 80

Figure 43. (continued).

Pediastrum boryanum (Figure 44)

This species was one of the earliest blooming green algae. Sporadic occurrences in April and early May preceded the maximum spatial distribution of this colony-forming alga in June and July. Moderate levels occurred at nearly all inner and middle Bay stations in June. By early August, its distribution had declined to only a few stations. From this time through November, occurrences of maximum abundance were mainly limited to near-river stations and stations in the eastern inner Bay.

Scenedesmus acutiformis (Figure 45)

This species is rarely reported from the Great Lakes. In Saginaw Bay, it reaches its maximum abundance and distribution in the inner and middle Bay. It first becomes abundant in August and reaches a maximum in September. Numbers decline from late September through November.

Scenedesmus decorus var. bicandato-granulatus (Figure 46)

Like S. spinosus, this species reached its maximum abundances at shallow water stations near the river and the eastern shore. Unlike S. spinosus, but like most other green algae, significant populations did not develop until July. In early July, distribution was limited to nearshore areas of the middle and inner Bay centered geographically around Wild Fowl Bay. By late July, this species reached its maximum cell densities and distribution. Its bay-wide abundance declined slowly and its distribution was erratic through November.

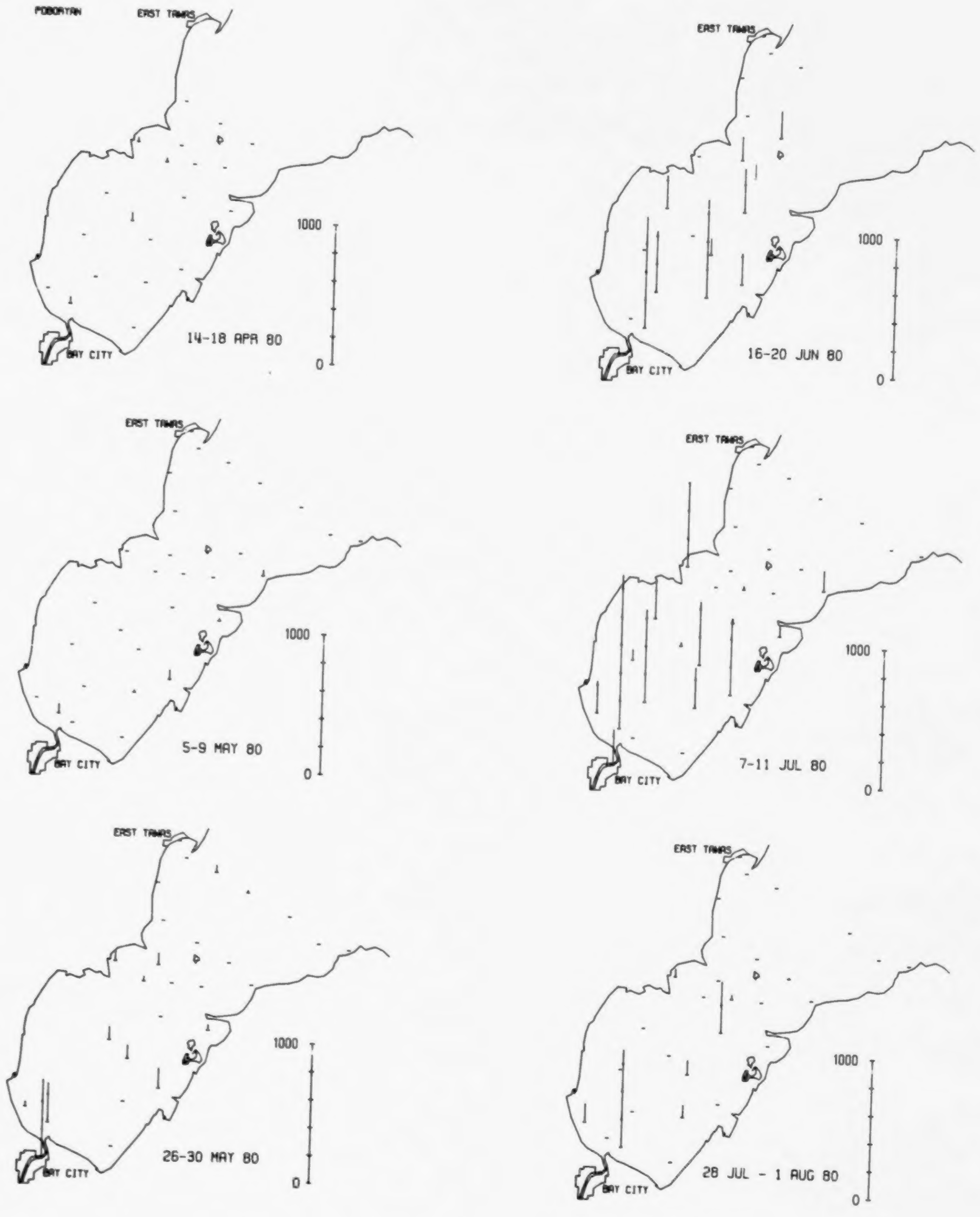

PDBORYAN
EAST TAWAS
BAY CITY
14-18 APR 80
1000
0
EAST TAWAS
BAY CITY
16-20 JUN 80
1000
0
EAST TAWAS
BAY CITY
5-9 MAY 80
1000
0
EAST TAWAS
BAY CITY
7-11 JUL 80
1000
0
EAST TAWAS
BAY CITY
26-30 MAY 80
1000
0
EAST TAWAS
BAY CITY
28 JUL - 1 AUG 80
1000
0

Figure 44. Distribution of Pediastrum boryanum.

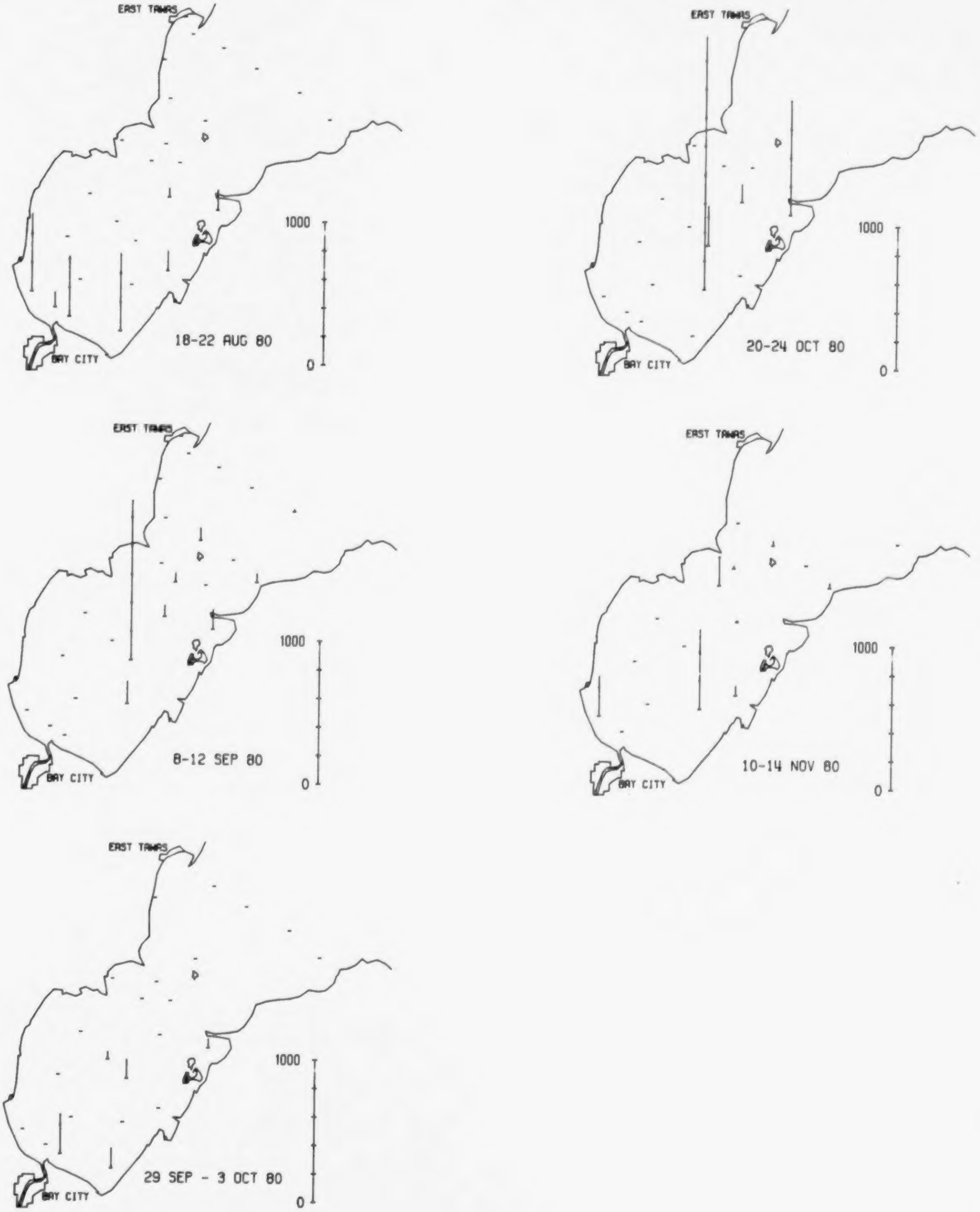

EAST TAWAS
BAY CITY
18-22 AUG 80
1000
0
EAST TAWAS
BAY CITY
20-24 OCT 80
1000
0
EAST TAWAS
BAY CITY
8-12 SEP 80
1000
0
EAST TAWAS
BAY CITY
10-14 NOV 80
1000
0
EAST TAWAS
BAY CITY
29 SEP - 3 OCT 80
1000
0

Figure 44. (continued).

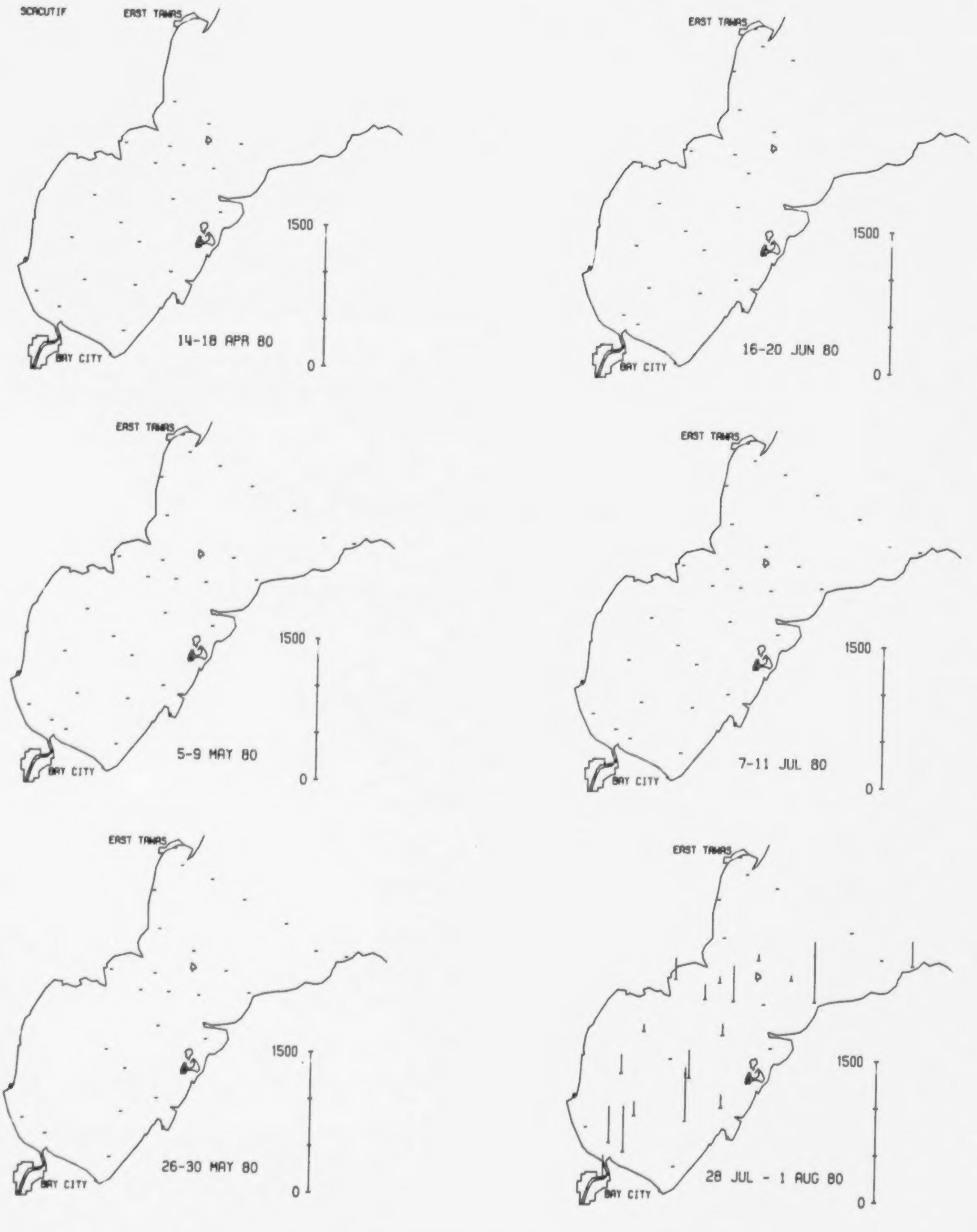

SCACUTIF
EAST TAWAS
BAY CITY
1500
0
14-18 APR 80
EAST TAWAS
BAY CITY
1500
0
16-20 JUN 80
EAST TAWAS
BAY CITY
1500
0
5-9 MAY 80
EAST TAWAS
BAY CITY
1500
0
7-11 JUL 80
EAST TAWAS
BAY CITY
1500
0
26-30 MAY 80
EAST TAWAS
BAY CITY
1500
0
28 JUL - 1 AUG 80

Figure 45. Distribution of Scenedesmus acutiformis.

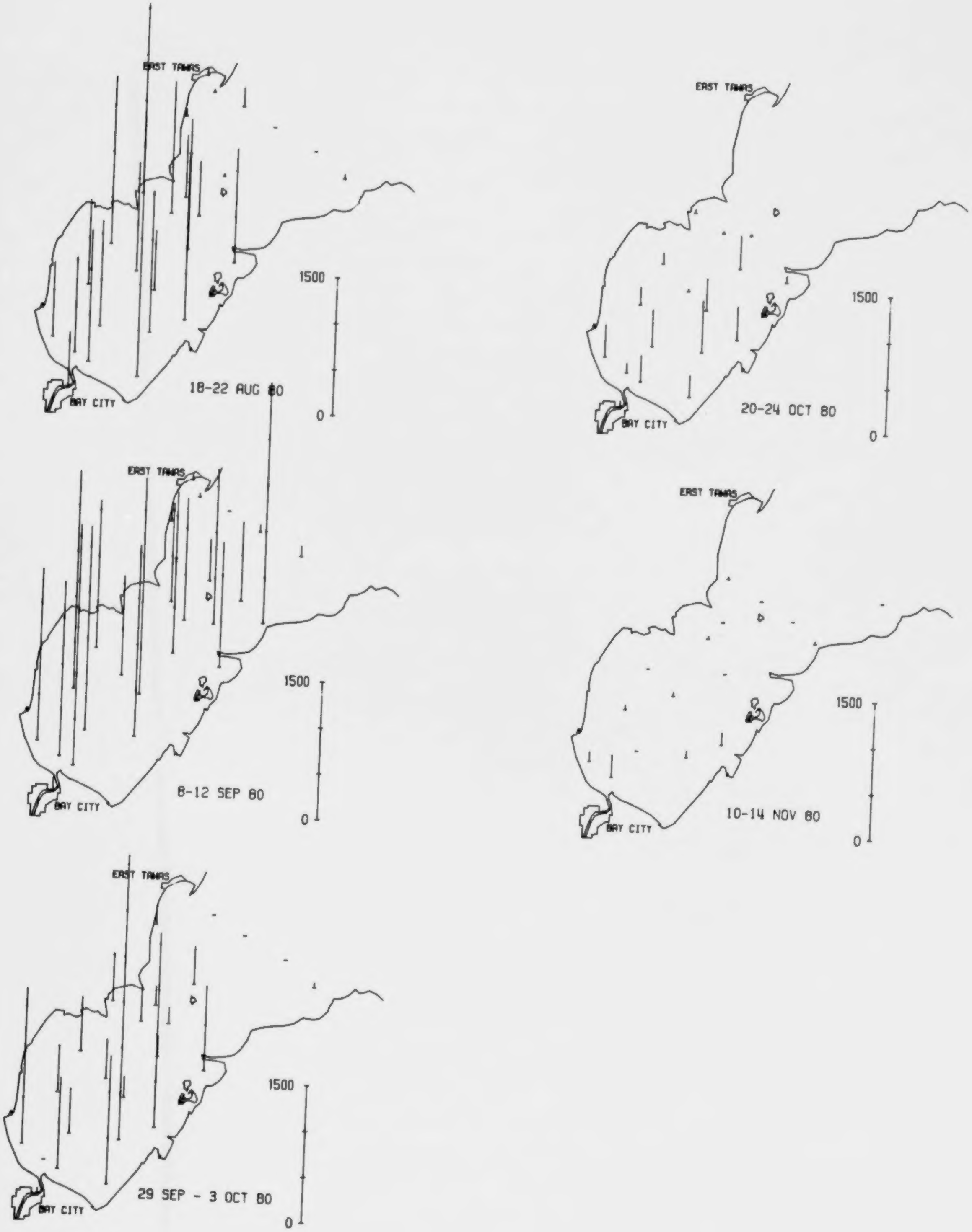

EAST TAWAS
BAY CITY
18-22 AUG 80
1500
0
EAST TAWAS
BAY CITY
20-24 OCT 80
1500
0
EAST TAWAS
BAY CITY
8-12 SEP 80
1500
0
EAST TAWAS
BAY CITY
10-14 NOV 80
1500
0
EAST TAWAS
BAY CITY
29 SEP - 3 OCT 80
1500
0

Figure 45. (continued).

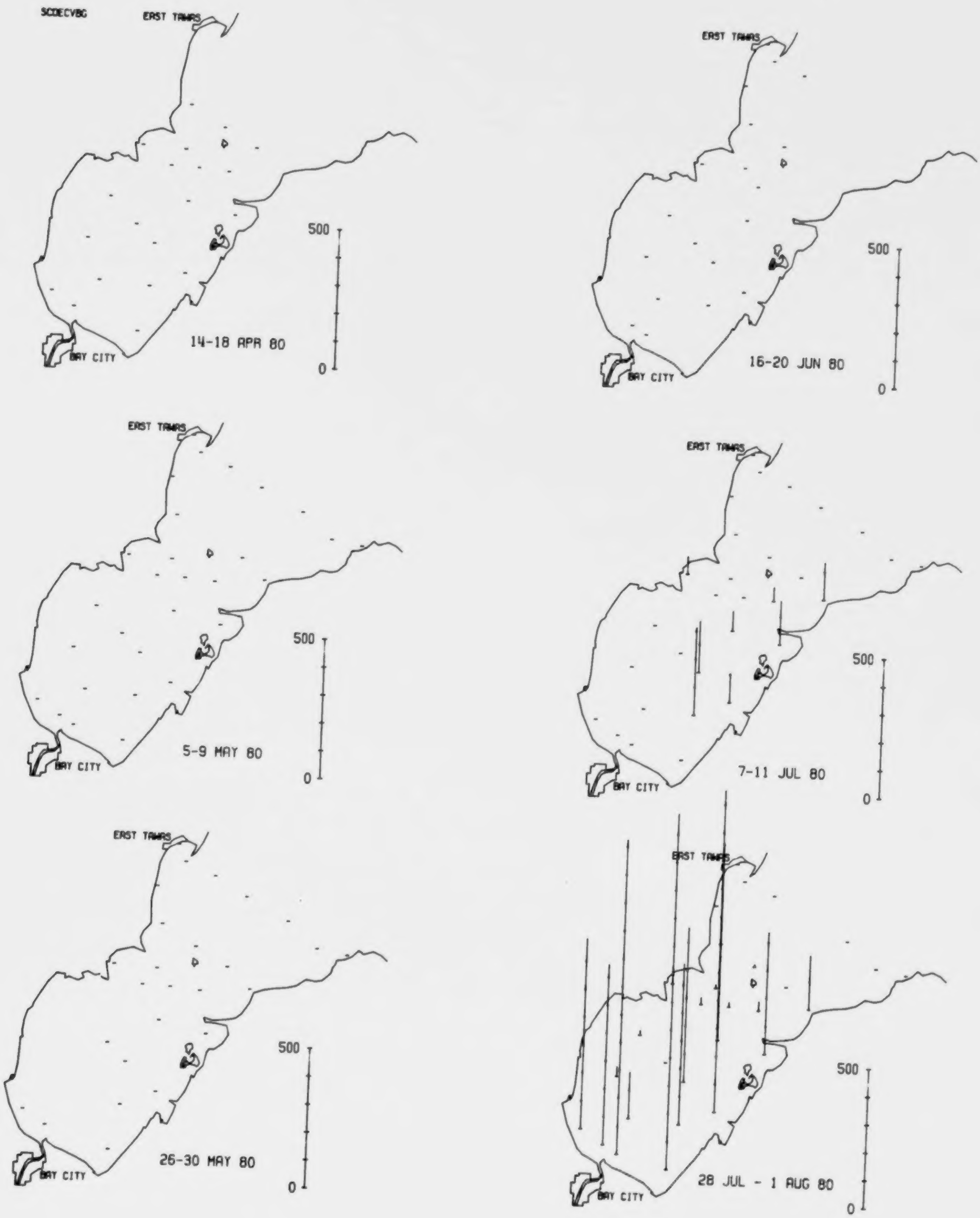

SCDECVBG
EAST TAWAS
BAY CITY
14-18 APR 80
500
0
16-20 JUN 80
5-9 MAY 80
7-11 JUL 80
26-30 MAY 80
28 JUL - 1 AUG 80

Figure 46. Distribution of Scenedesmus decorus var. bicaudato-granulatus.

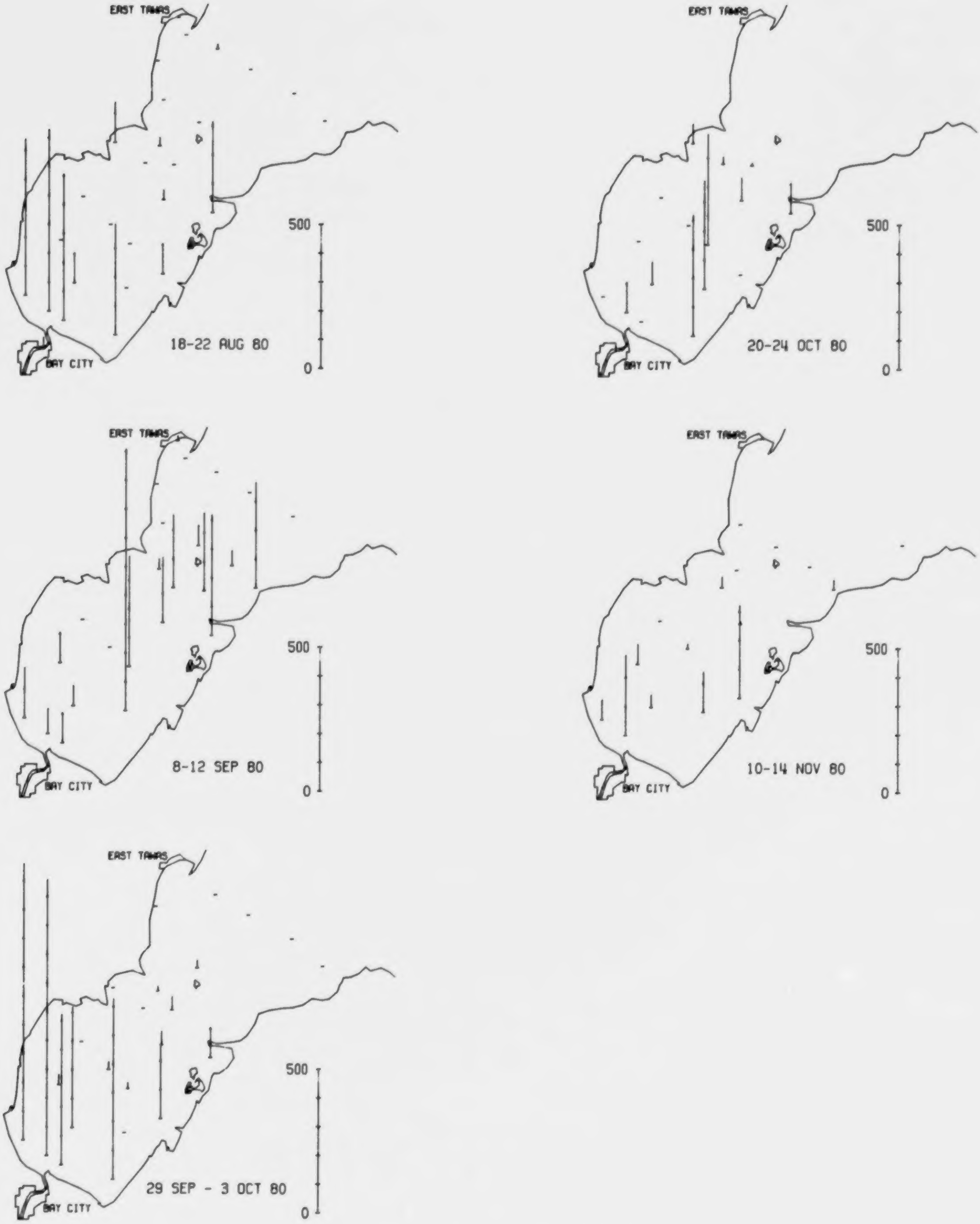

EAST TAWAS
BAY CITY
18-22 AUG 80
500
0
EAST TAWAS
BAY CITY
20-24 OCT 80
500
0
EAST TAWAS
BAY CITY
8-12 SEP 80
500
0
EAST TAWAS
BAY CITY
10-14 NOV 80
500
0
EAST TAWAS
BAY CITY
29 SEP - 3 OCT 80
500
0

Figure 46. (continued).

Scenedesmus spinosus (Figure 47)

This was one of the most frequently occurring chlorophytes of this study. It was unusual among green algae in that it occurred in at least moderate abundance in early spring, developing significant populations by late May, and persisted in high numbers through November. Its highest densities were restricted to nearshore areas, both near the river and in the eastern inner Bay, into Wild Fowl Bay. In the outer Bay, low to moderate densities were observed near Charity Island, Oak Point, and the Bay-like interface at stations 52 and 53.

Cryptophyta or cryptomonads (Figure 48)

The cryptomonads are common in all types of fresh and brackish bodies of water. In Saginaw Bay, highest abundances are reached in the inner Bay, but this division is common at all stations at the interface of the Bay and Lake Huron. Seasonally, highest abundance occur in late spring to early summer and in late September but these peaks are not strong ones.

Chroomonas spp. (Figure 49)

These flagellated organisms have only recently been recognized as part of the Great Lakes flora. Their spatial distribution is fairly uniform in Saginaw Bay, although inner Bay stations, especially near the river and nearshore stations, have slightly higher abundances. Seasonally, a slight increase occurred between April and May. By June numbers had decreased across most of the Bay. Cell densities increased slightly in August, increased in September, and again decreased through November.

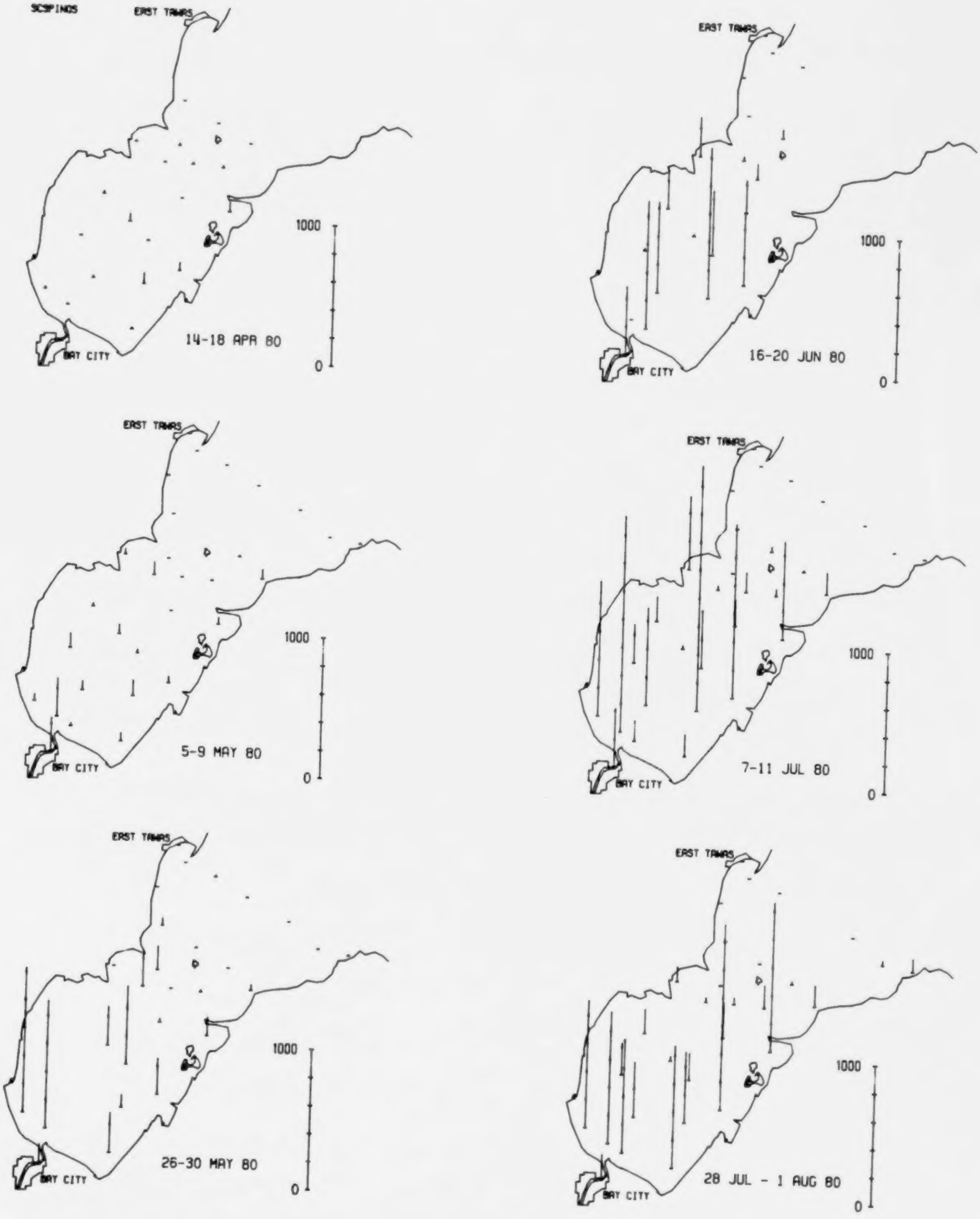

SCSPINOS
EAST TAWAS
BAY CITY
1000
0
14-18 APR 80
16-20 JUN 80
5-9 MAY 80
7-11 JUL 80
26-30 MAY 80
28 JUL - 1 AUG 80

Figure 47. **Distribution of** **Scenedesmus** **spinosus.**

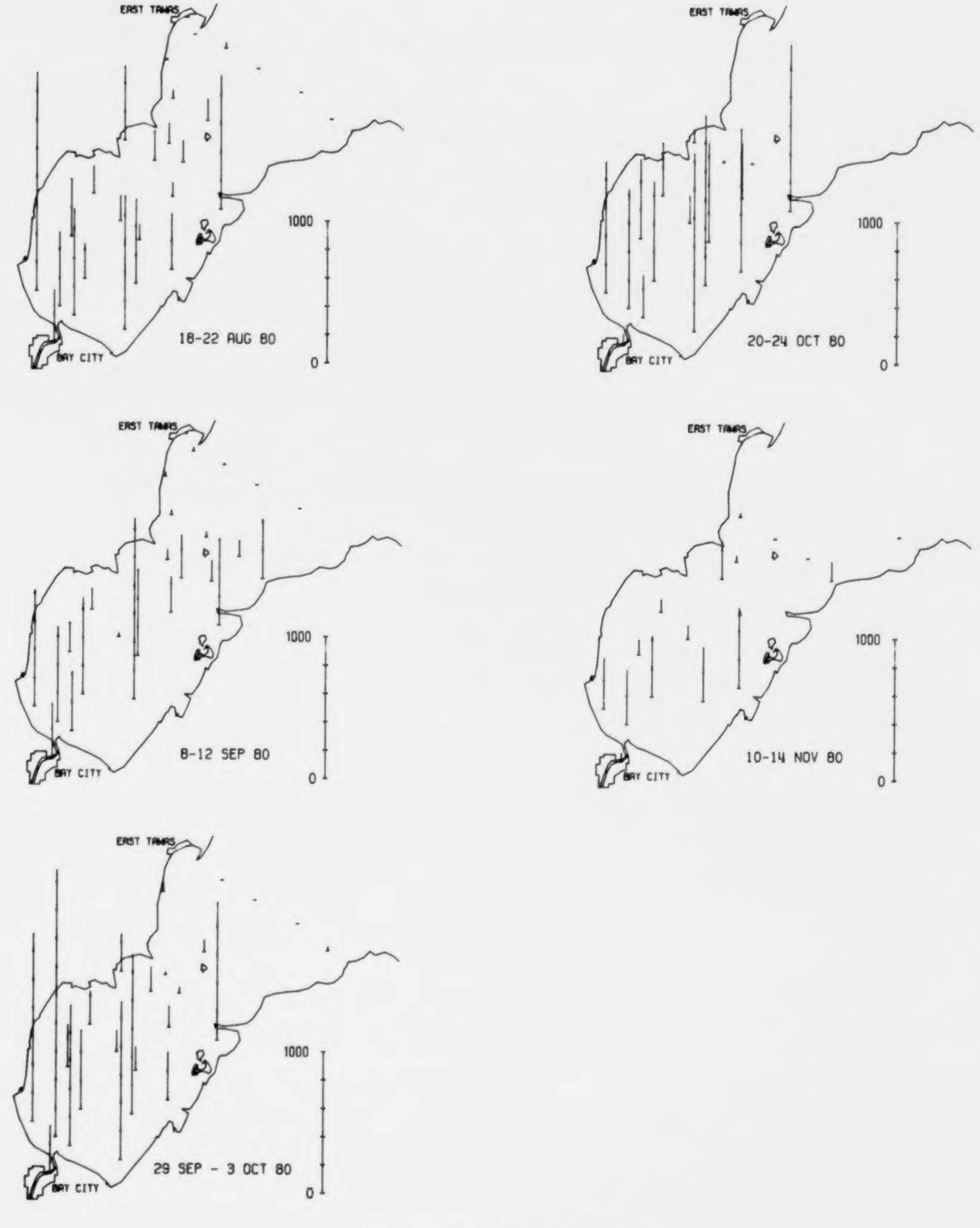

EAST TAWAS
BAY CITY
1000
0
18-22 AUG 80
20-24 OCT 80
8-12 SEP 80
10-14 NOV 80
29 SEP - 3 OCT 80

Figure 47. (continued).

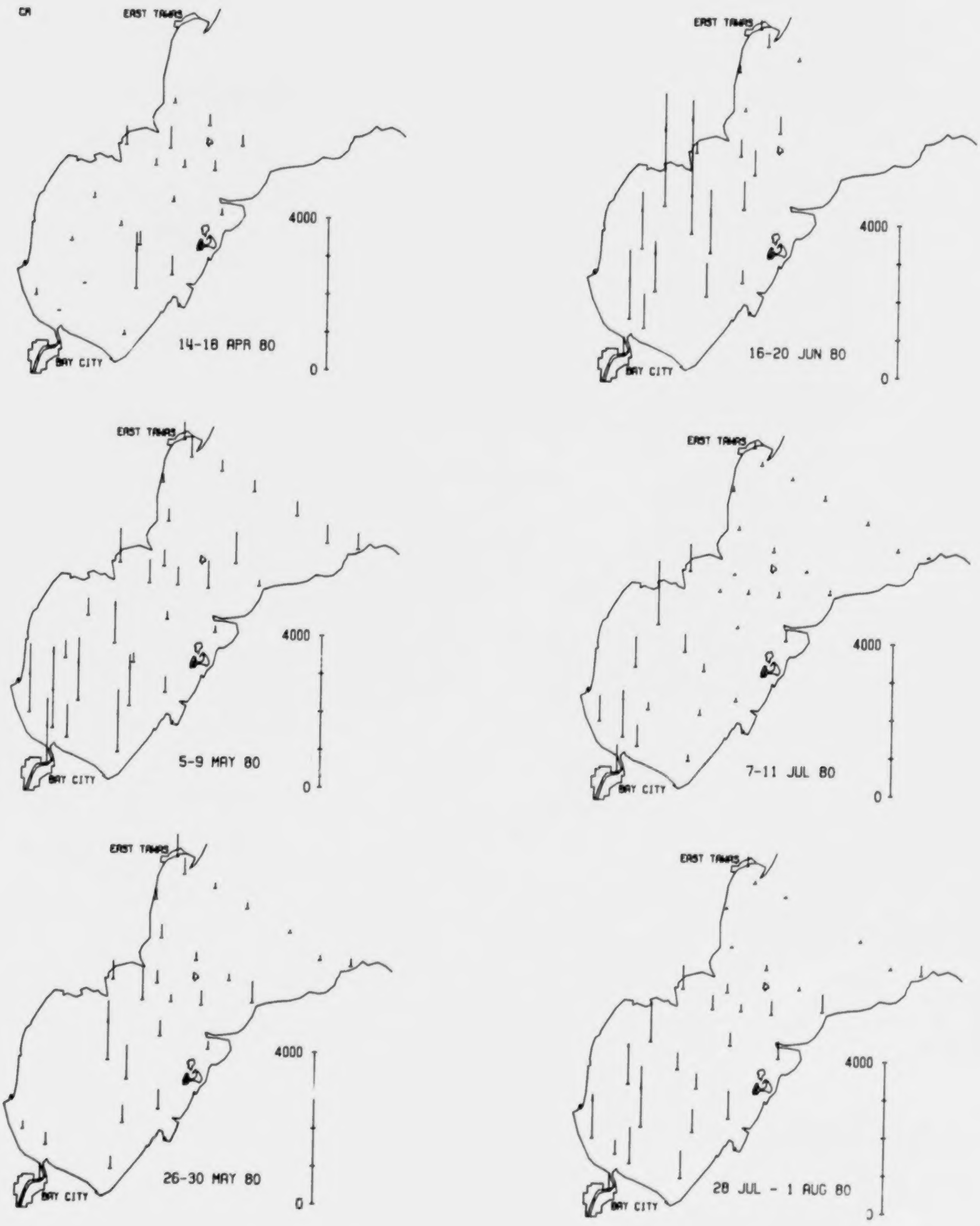

CA
EAST TAWAS
BAY CITY
4000
0
14-18 APR 80
16-20 JUN 80
5-9 MAY 80
7-11 JUL 80
26-30 MAY 80
28 JUL - 1 AUG 80

Figure 48. Distribution of cryptomonads.

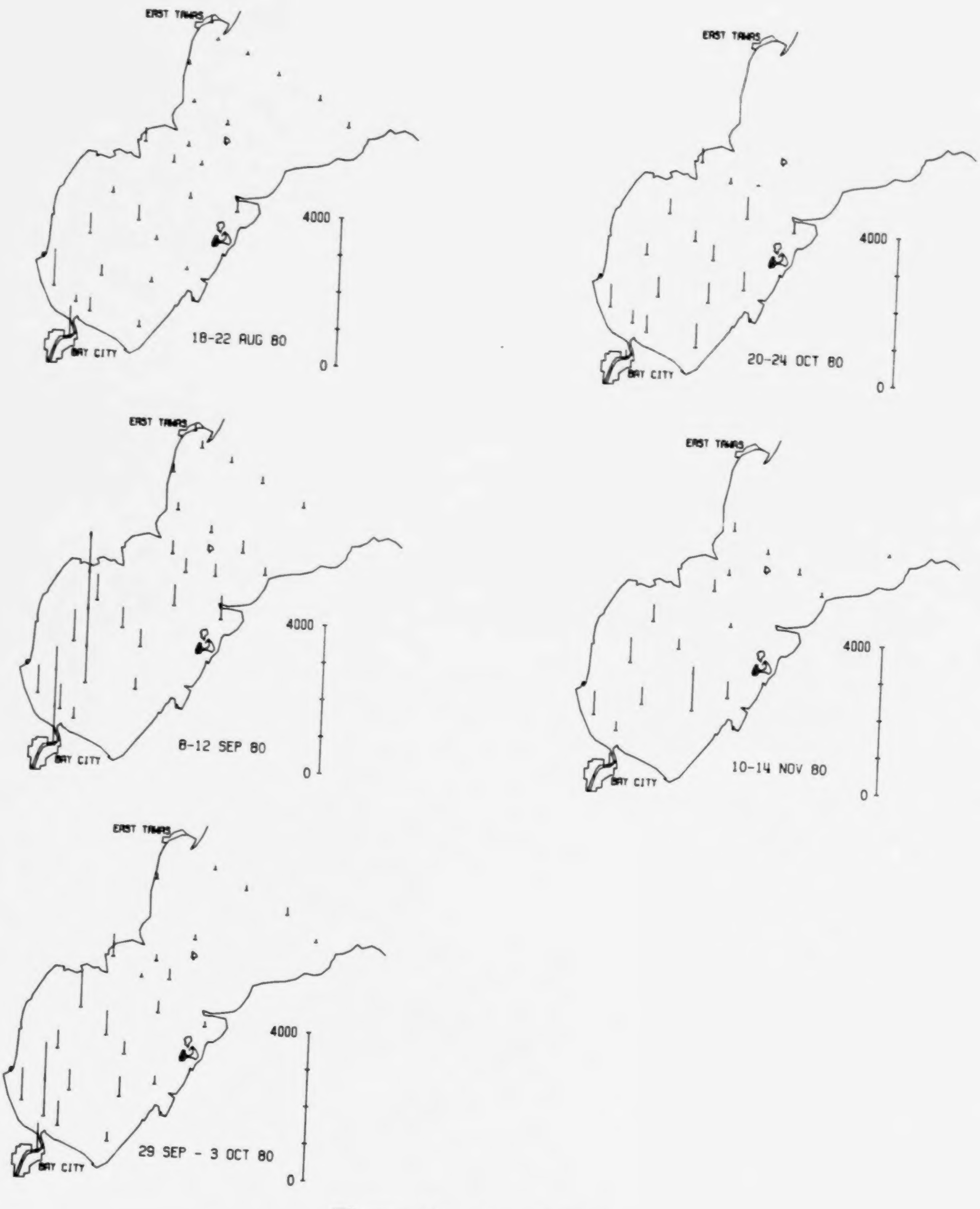

EAST TAWAS
BAY CITY
4000
0
18-22 AUG 80
EAST TAWAS
BAY CITY
4000
0
20-24 OCT 80
EAST TAWAS
BAY CITY
4000
0
8-12 SEP 80
EAST TAWAS
BAY CITY
4000
0
10-14 NOV 80
EAST TAWAS
BAY CITY
4000
0
29 SEP - 3 OCT 80

Figure 48. (continued).

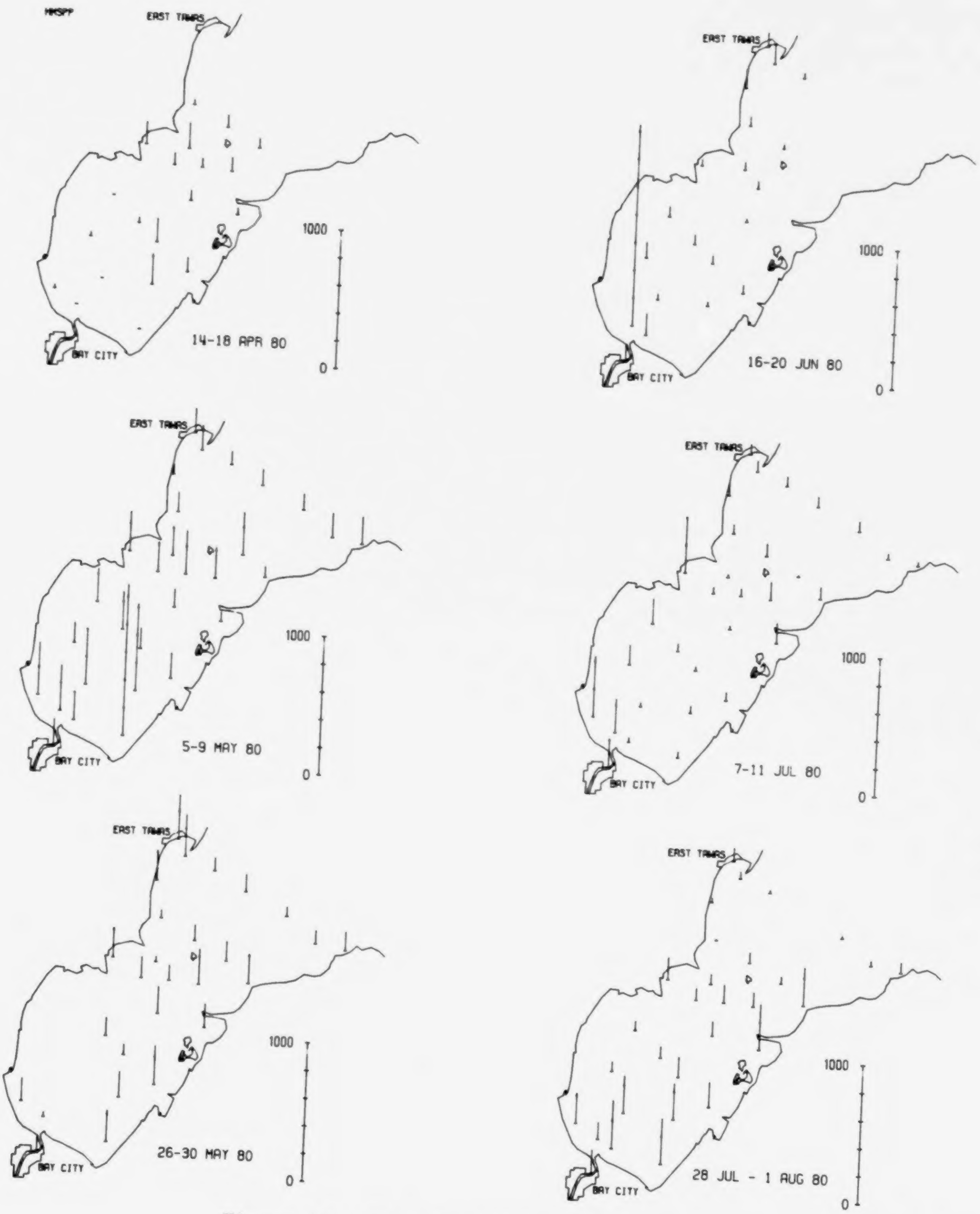

HHSPP
EAST TAWAS
BAY CITY
14-18 APR 80
1000
0
EAST TAWAS
BAY CITY
16-20 JUN 80
1000
0
EAST TAWAS
BAY CITY
5-9 MAY 80
1000
0
EAST TAWAS
BAY CITY
7-11 JUL 80
1000
0
EAST TAWAS
BAY CITY
26-30 MAY 80
1000
0
EAST TAWAS
BAY CITY
28 JUL - 1 AUG 80
1000
0

Figure 49. Distribution of Chroomonas spp.

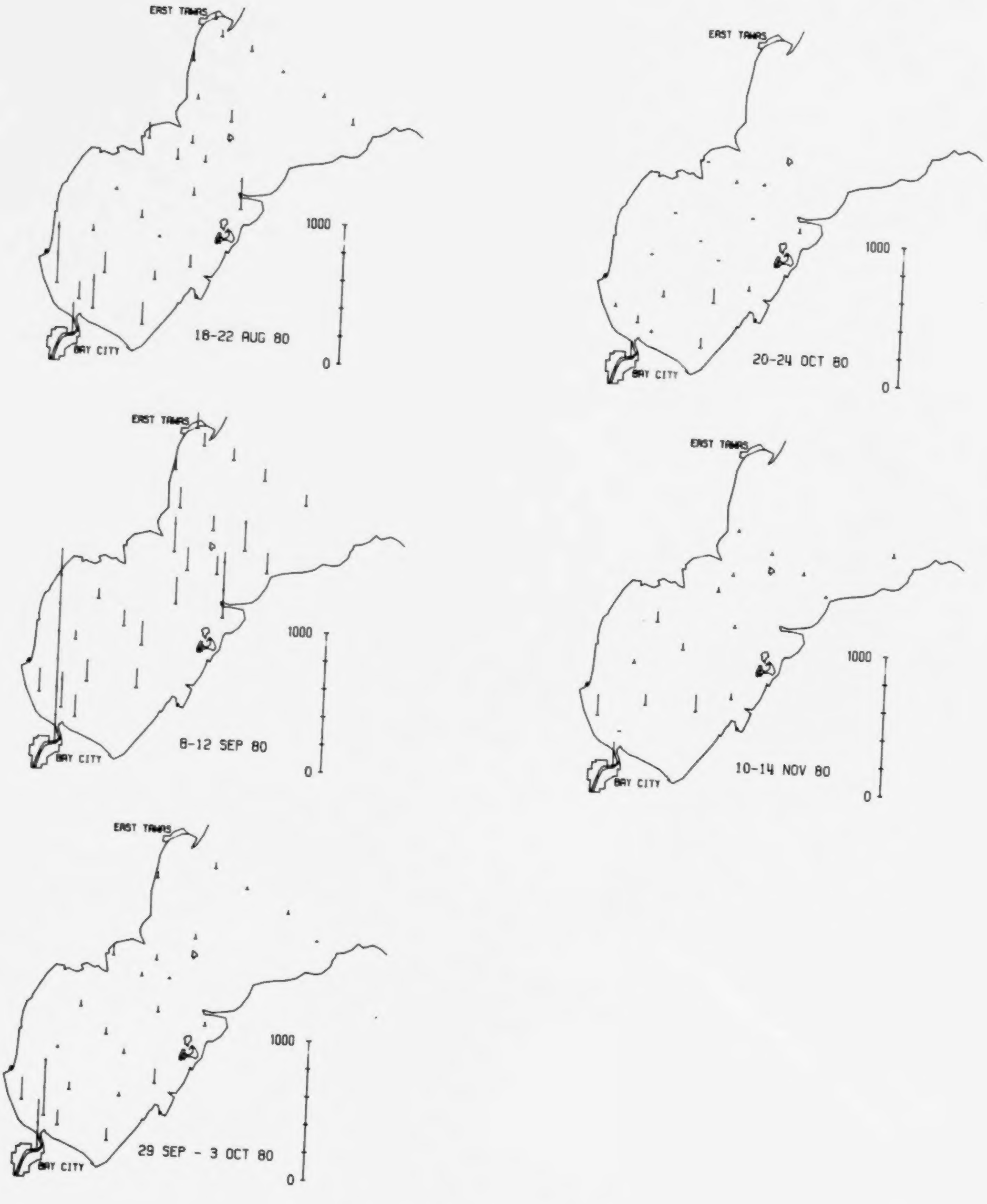

EAST TAWAS
BAY CITY
18-22 AUG 80
1000
0
EAST TAWAS
BAY CITY
20-24 OCT 80
1000
0
EAST TAWAS
BAY CITY
8-12 SEP 80
1000
0
EAST TAWAS
BAY CITY
10-14 NOV 80
1000
0
EAST TAWAS
BAY CITY
29 SEP - 3 OCT 80
1000
0

Figure 49. (continued).

Cryptomonas ovata (Figure 50)

This species is common in the upper Great Lakes. Although it was present in all portions of Saginaw Bay through most of the year, maximum abundances of this species occurred in June in the inner Bay, and occurrences at the Bay-Lake Huron interface were sporadic.

Rhodomonas minuta (Figure 51)

This species has been observed throughout the upper Great Lakes, in both inshore and offshore waters. In Saginaw Bay, this species occurs at all stations and in all seasons. There is a tendency for higher cell densities in both May and June, and then again in September, and at stations in the western half of the inner Bay. In early May, cell densities are moderately high at the Bay-Lake interface stations, indicating that this species is relatively important in this region in the spring.

Chrysophyta or chrysophytes (Figure 52)

Many of the species of this group are reported from oligotrophic to mesotrophic waters, but individual species may form blooms under a wide variety of conditions. In Saginaw Bay, only moderate abundances of representatives of this Division ever develop. Greatest cell densities occur in nearshore stations on both sides of the Bay. Excluding nearshore stations, inner and outer Bay stations have roughly equal abundances of this Division. This, along with total phytoplankton data (Appendix 1), indicates that chrysophytes are relatively important at outer Bay stations.

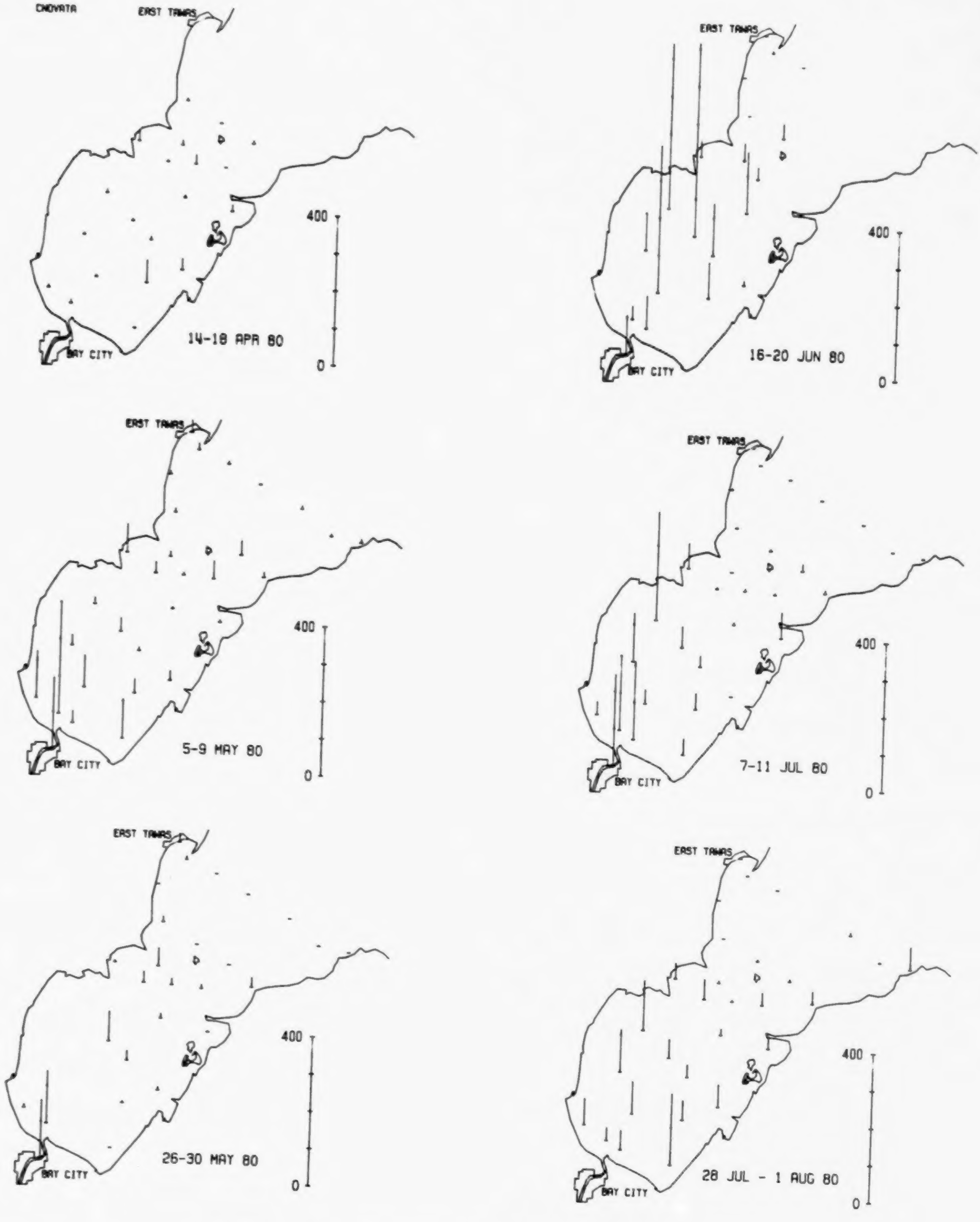

CNOVATA
EAST TAWAS
BAY CITY
14-18 APR 80
400
0
EAST TAWAS
BAY CITY
16-20 JUN 80
400
0
EAST TAWAS
BAY CITY
5-9 MAY 80
400
0
EAST TAWAS
BAY CITY
7-11 JUL 80
400
0
EAST TAWAS
BAY CITY
26-30 MAY 80
400
0
EAST TAWAS
BAY CITY
28 JUL - 1 AUG 80
400
0

Figure 50. Distribution of Cryptomonas ovata.

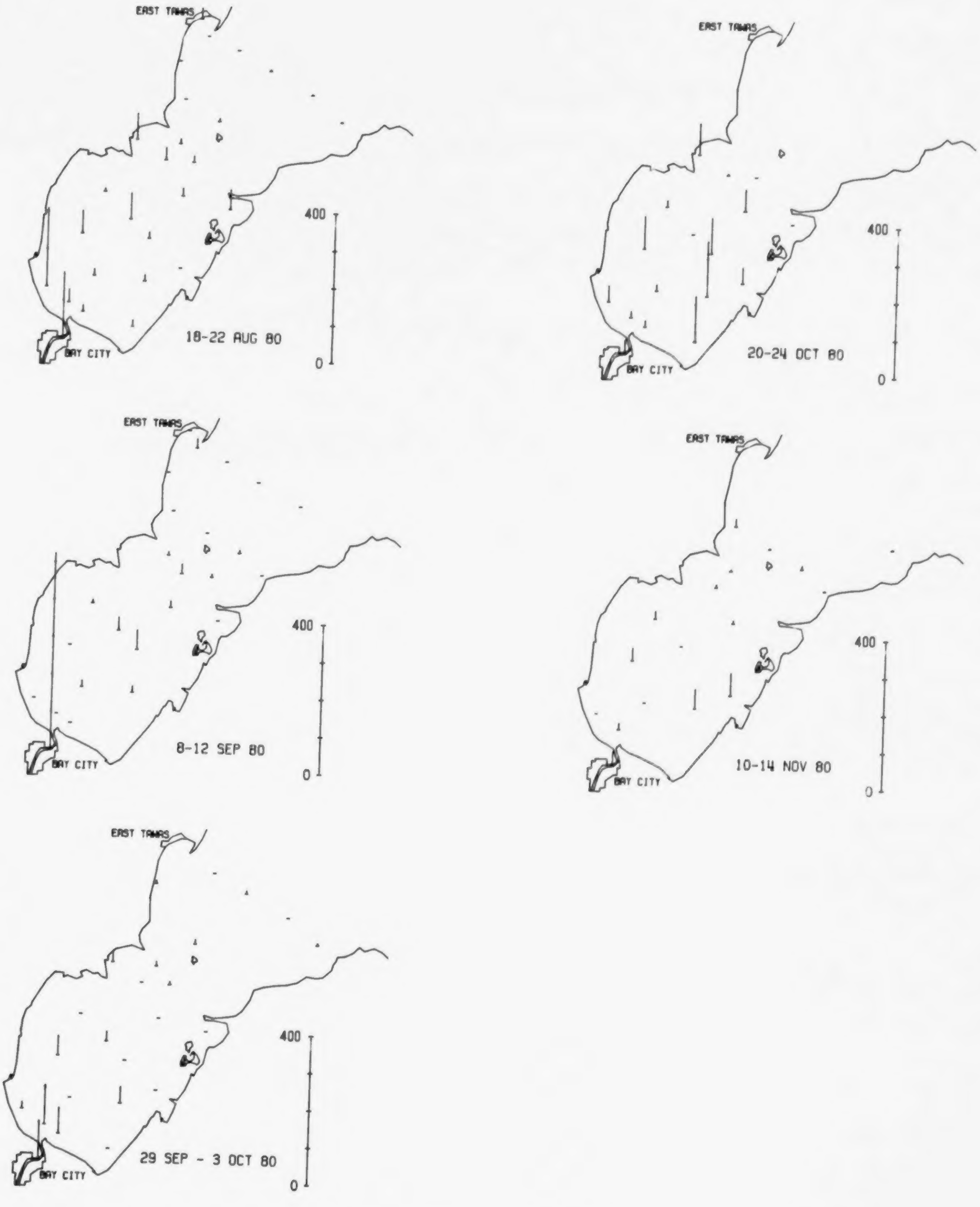

EAST TAWAS
BAY CITY
18-22 AUG 80
400
0
EAST TAWAS
BAY CITY
20-24 OCT 80
400
0
EAST TAWAS
BAY CITY
8-12 SEP 80
400
0
EAST TAWAS
BAY CITY
10-14 NOV 80
400
0
EAST TAWAS
BAY CITY
29 SEP - 3 OCT 80
400
0

Figure 50. (continued).

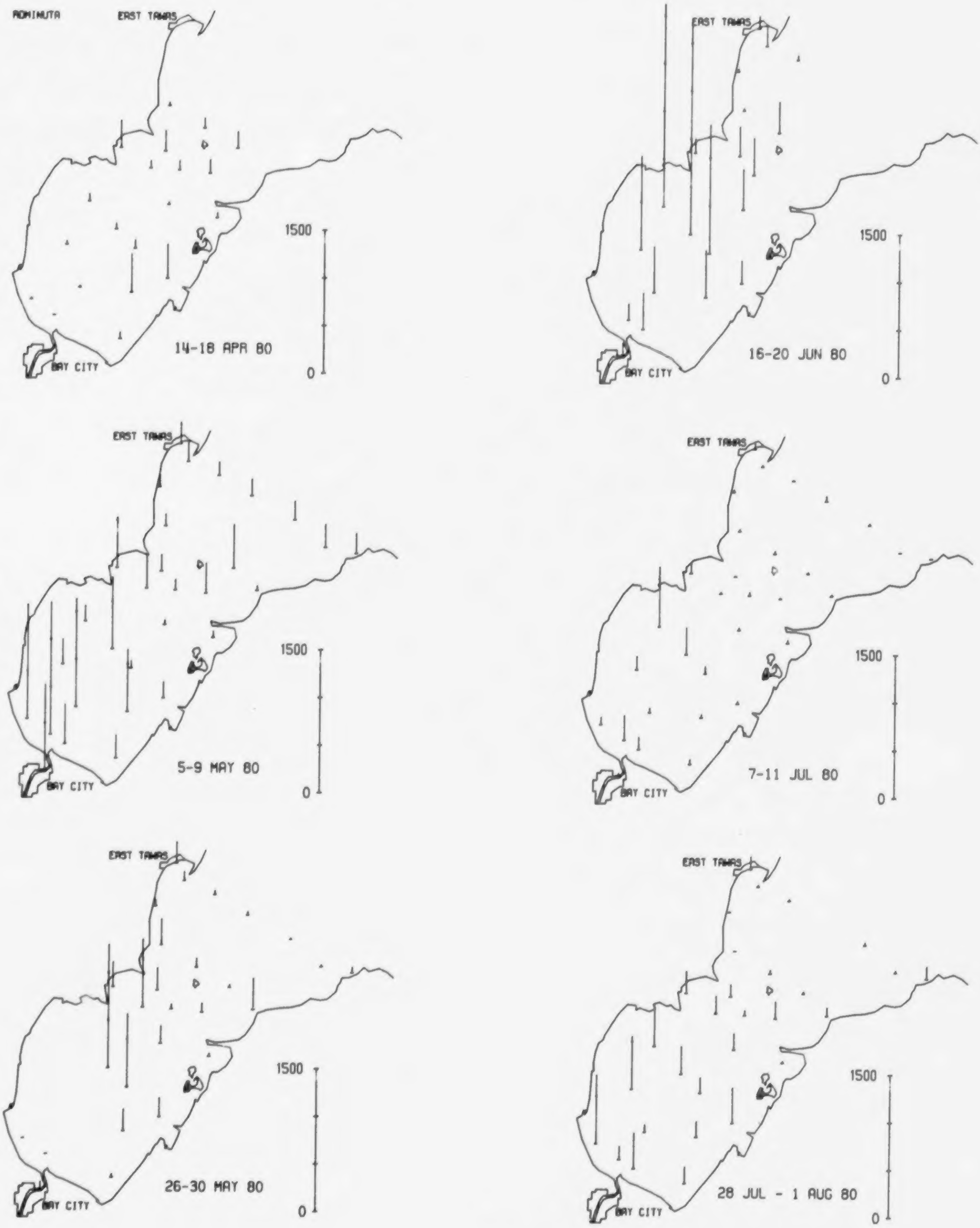

RDMINUTA
EAST TAWAS
BAY CITY
1500
0
14-18 APR 80
EAST TAWAS
BAY CITY
1500
0
16-20 JUN 80
EAST TAWAS
BAY CITY
1500
0
5-9 MAY 80
EAST TAWAS
BAY CITY
1500
0
7-11 JUL 80
EAST TAWAS
BAY CITY
1500
0
26-30 MAY 80
EAST TAWAS
BAY CITY
1500
0
28 JUL - 1 AUG 80

Figure 51. Distribution of Rhodomonas minuta.

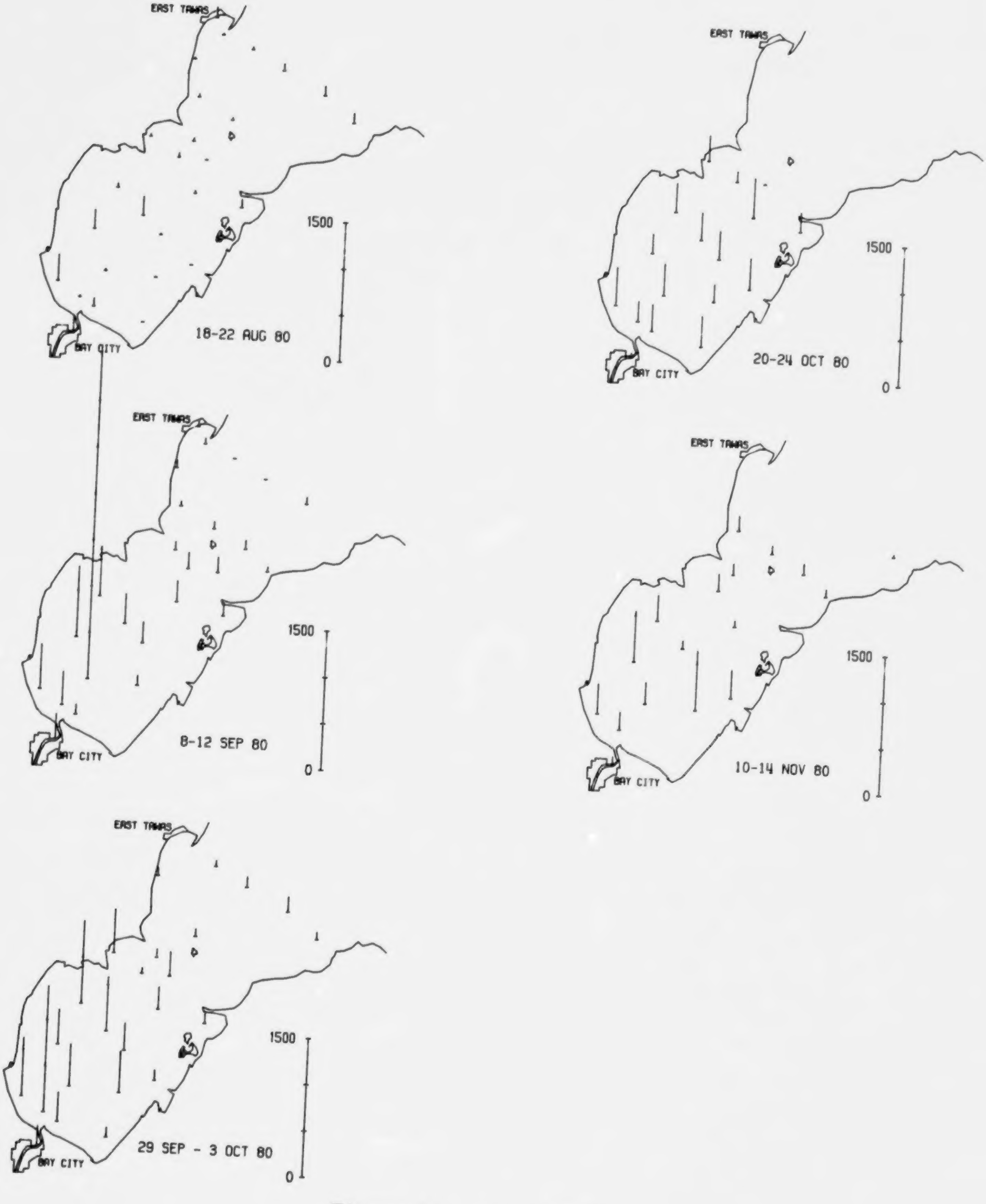

EAST TAWAS
BAY CITY
1500
0
18-22 AUG 80
EAST TAWAS
BAY CITY
1500
0
20-24 OCT 80
EAST TAWAS
BAY CITY
1500
0
8-12 SEP 80
EAST TAWAS
BAY CITY
1500
0
10-14 NOV 80
EAST TAWAS
BAY CITY
1500
0
29 SEP - 3 OCT 80

Figure 51. (continued).

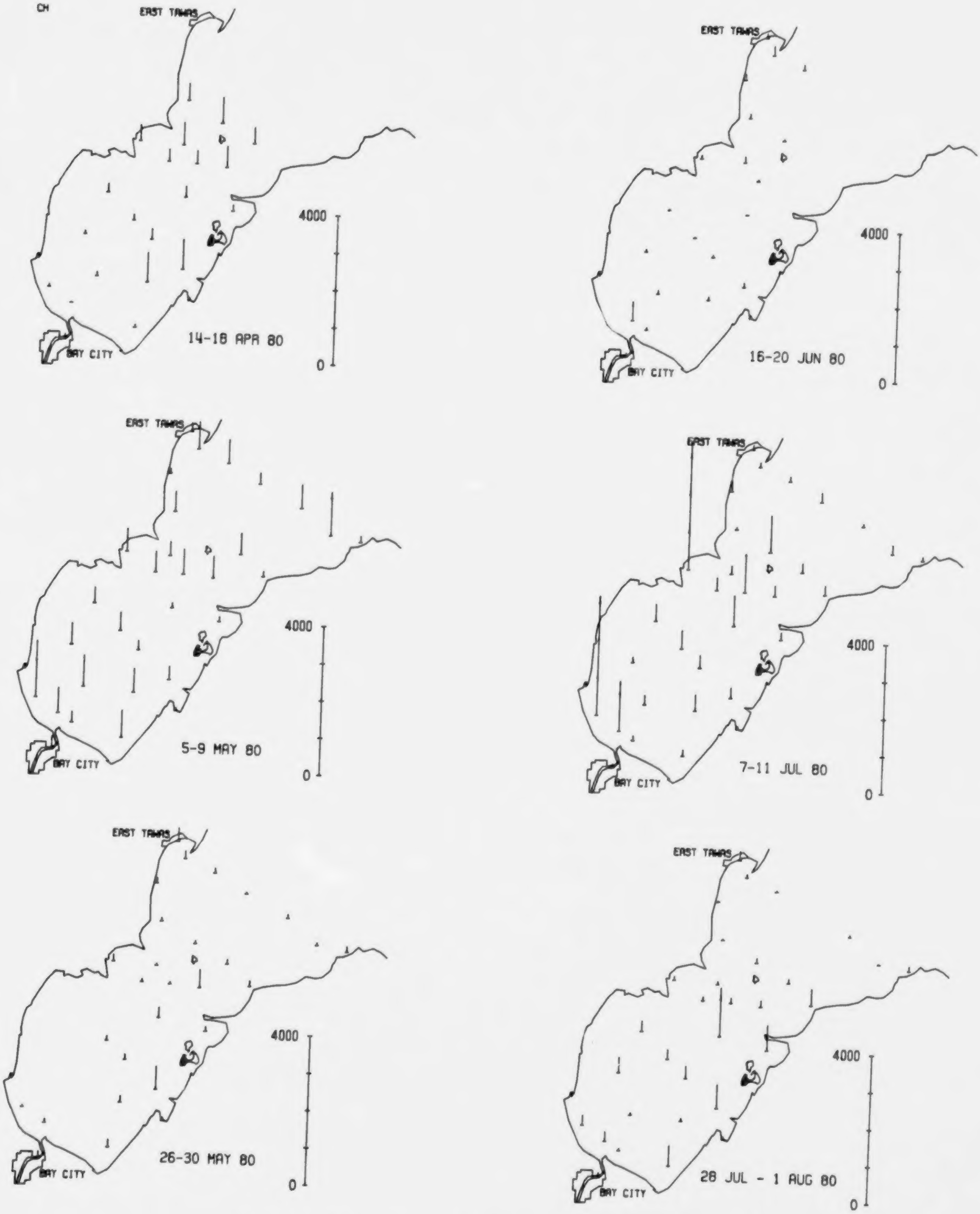

CH
EAST TAWAS
BAY CITY
14-18 APR 80
4000
0
EAST TAWAS
BAY CITY
16-20 JUN 80
4000
0
EAST TAWAS
BAY CITY
5-9 MAY 80
4000
0
EAST TAWAS
BAY CITY
7-11 JUL 80
4000
0
EAST TAWAS
BAY CITY
26-30 MAY 80
4000
0
EAST TAWAS
BAY CITY
28 JUL - 1 AUG 80
4000
0

Figure 52. Distribution of chrysophytes.

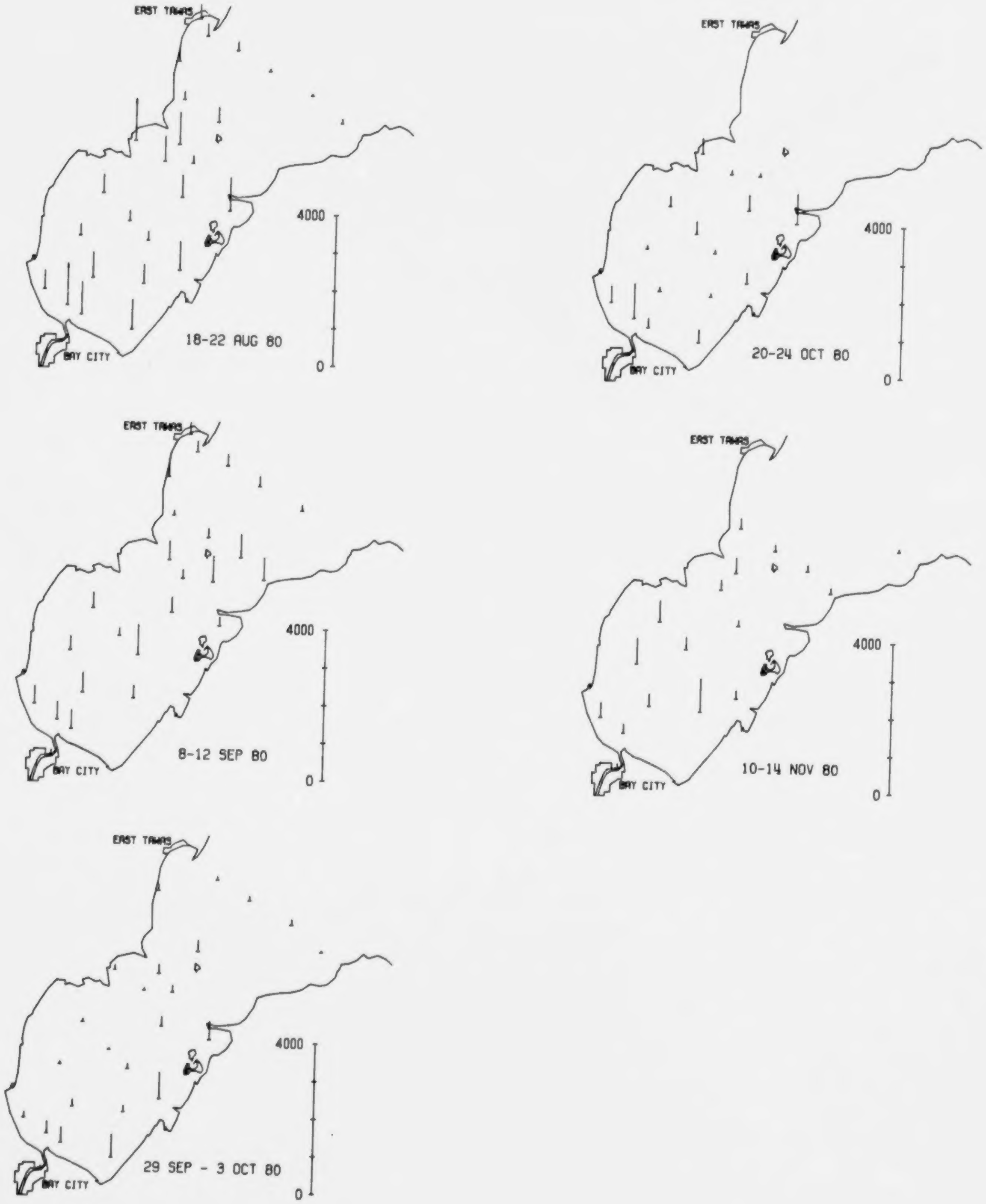

EAST TAWAS
BAY CITY
18-22 AUG 80
4000
0
EAST TAWAS
BAY CITY
20-24 OCT 80
4000
0
EAST TAWAS
BAY CITY
8-12 SEP 80
4000
0
EAST TAWAS
BAY CITY
10-14 NOV 80
4000
0
EAST TAWAS
BAY CITY
29 SEP - 3 OCT 80
4000
0

Figure 52. (continued).

Ochromonas spp. (Figure 53)

These organisms are common in all areas of the upper Great Lakes. In Saginaw Bay, late May densities are highest at Bay-Lake interface stations but it is present at all stations. By late May, numbers have decreased in most areas remaining high at a few stations surrounding, but not including, Wild Fowl Bay. In July, pulses occur at nearshore stations on the western side of the Bay, the maximum being reached near Point Au Gres. From then through November, distribution and abundance remains uniform except for a strong tendency to very low abundances at the Bay-Lake interface, reversing the May trend.

Undetermined flagellates (Figure 54)

This category is likely composed of small Chrysophyta and Haptophyta whose specific affinities cannot be accurately determined with standard light microscope techniques (Stoermer and Sicko-Goad 1977). May cell densities were the highest for most stations. However, Wild Fowl Bay and stations in and near the Saginaw River exhibited sporadic pulses from June through November.

Flagellate species #13 (Figure 55)

This taxon reached its greatest abundance in nearshore areas of the Bay. In April moderate densities occurred in the middle Bay near Charity Island. In May it reached its broadest distribution, although cell densities were greatest along both shores. Low to moderate abundances characterized the middle and outer Bay from June through August. Moderate to low densities persist in scattered locations in the middle and inner Bay from late October through November.

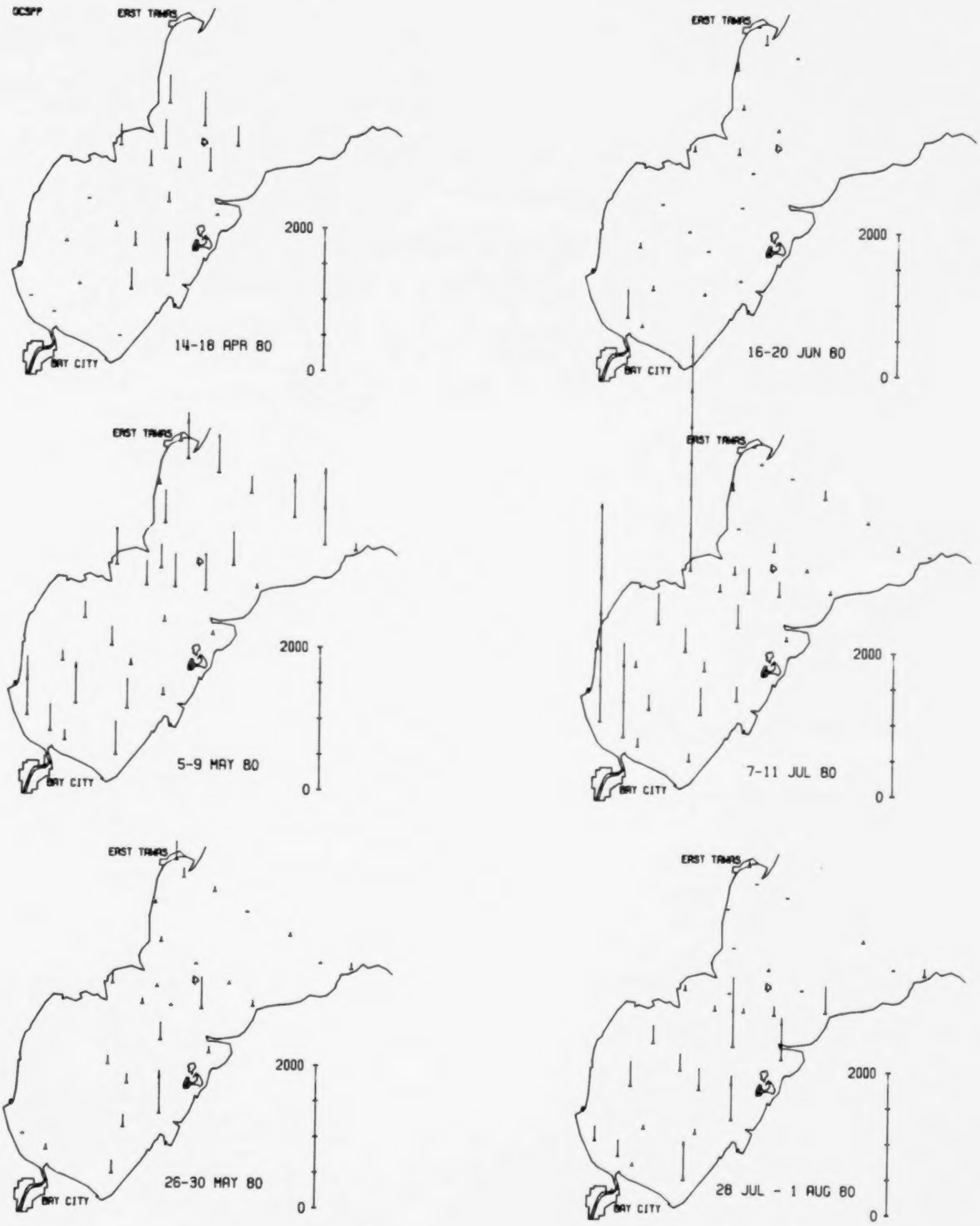

OCSPP
EAST TAWAS
BAY CITY
2000
0
14-18 APR 80
16-20 JUN 80
5-9 MAY 80
7-11 JUL 80
26-30 MAY 80
28 JUL - 1 AUG 80

Figure 53. Distribution of Ochromonas spp.

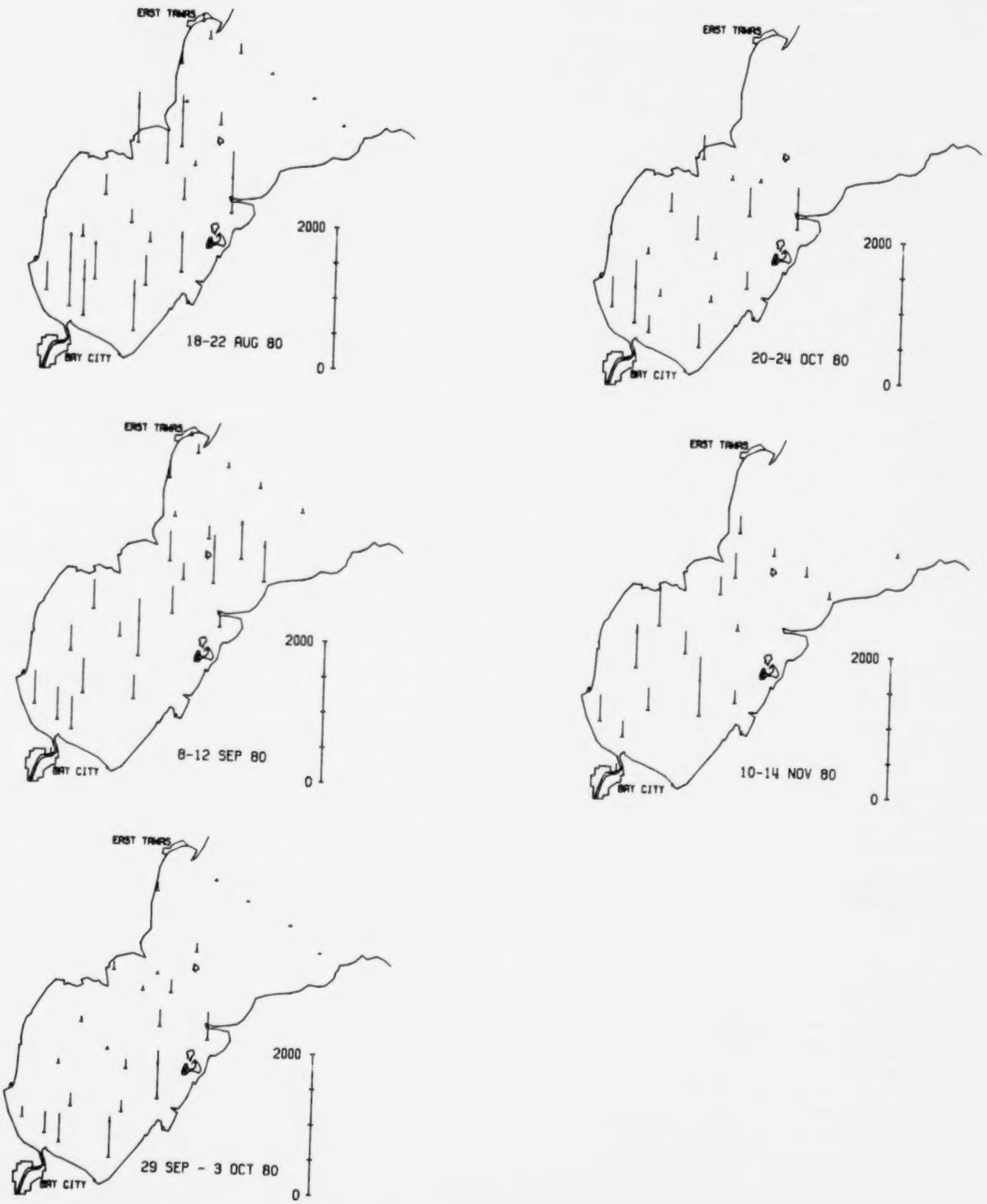

EAST TAWAS
BAY CITY
18-22 AUG 80
2000
0
EAST TAWAS
BAY CITY
20-24 OCT 80
2000
0
EAST TAWAS
BAY CITY
8-12 SEP 80
2000
0
EAST TAWAS
BAY CITY
10-14 NOV 80
2000
0
EAST TAWAS
BAY CITY
29 SEP - 3 OCT 80
2000
0

Figure 53. (continued).

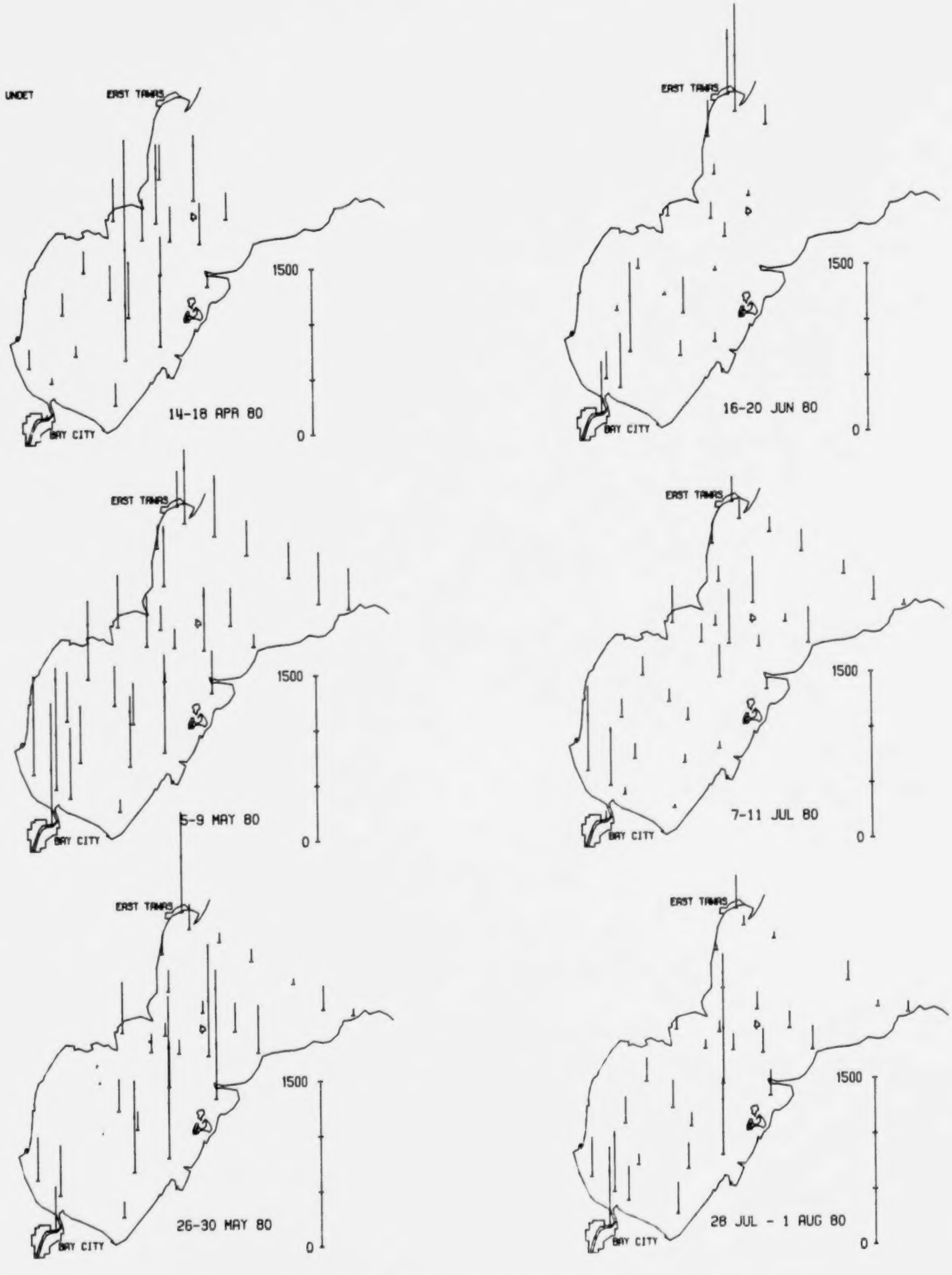

UNDET
EAST TAWAS
BAY CITY
1500
0
14-18 APR 80
16-20 JUN 80
5-9 MAY 80
7-11 JUL 80
26-30 MAY 80
28 JUL - 1 AUG 80

Figure 54. Distribution of undetermined flagellates.

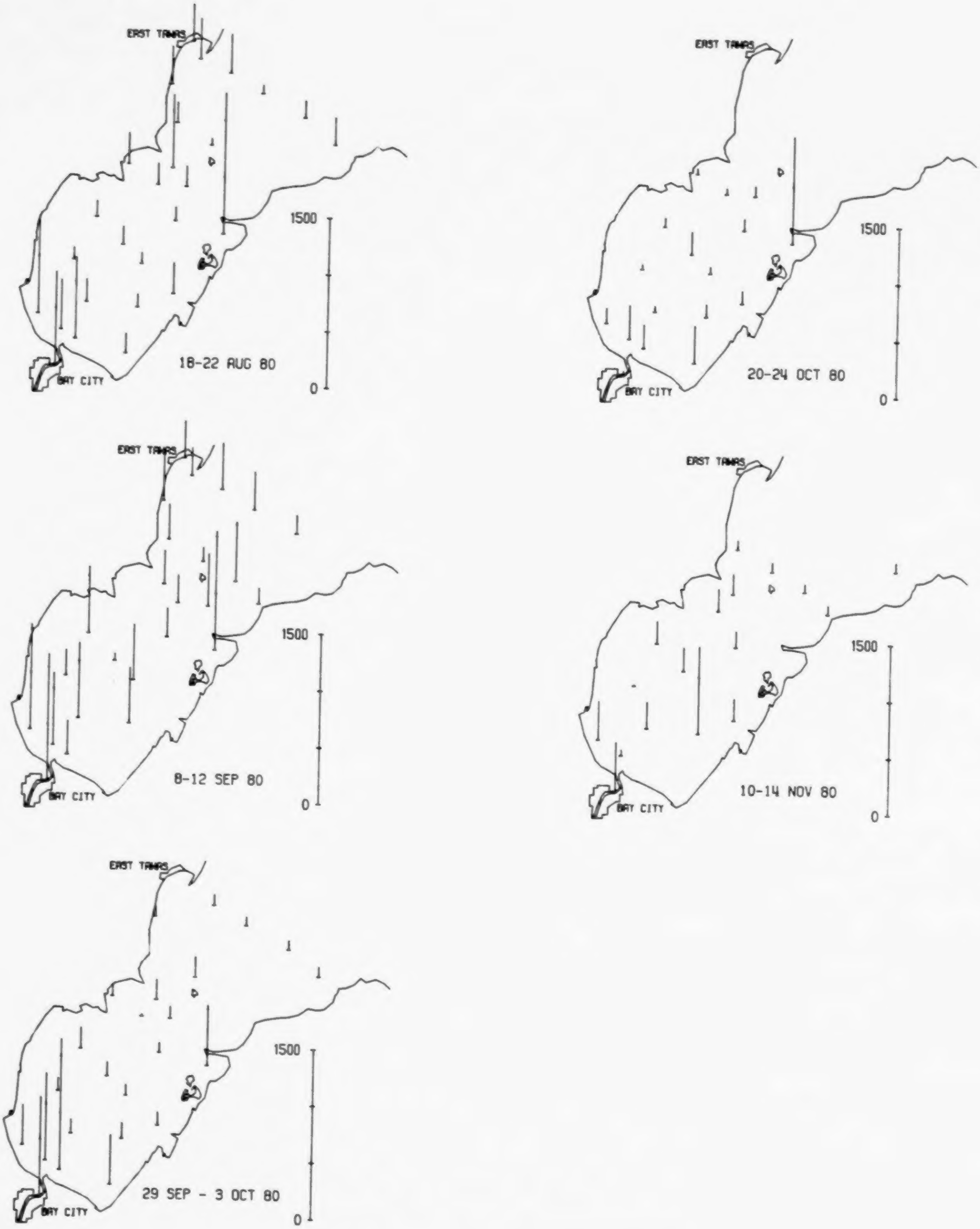

EAST TAWAS
BAY CITY
1500
0
18-22 AUG 80
EAST TAWAS
BAY CITY
1500
0
20-24 OCT 80
EAST TAWAS
BAY CITY
1500
0
8-12 SEP 80
EAST TAWAS
BAY CITY
1500
0
10-14 NOV 80
EAST TAWAS
BAY CITY
1500
0
29 SEP - 3 OCT 80

Figure 54. (continued).

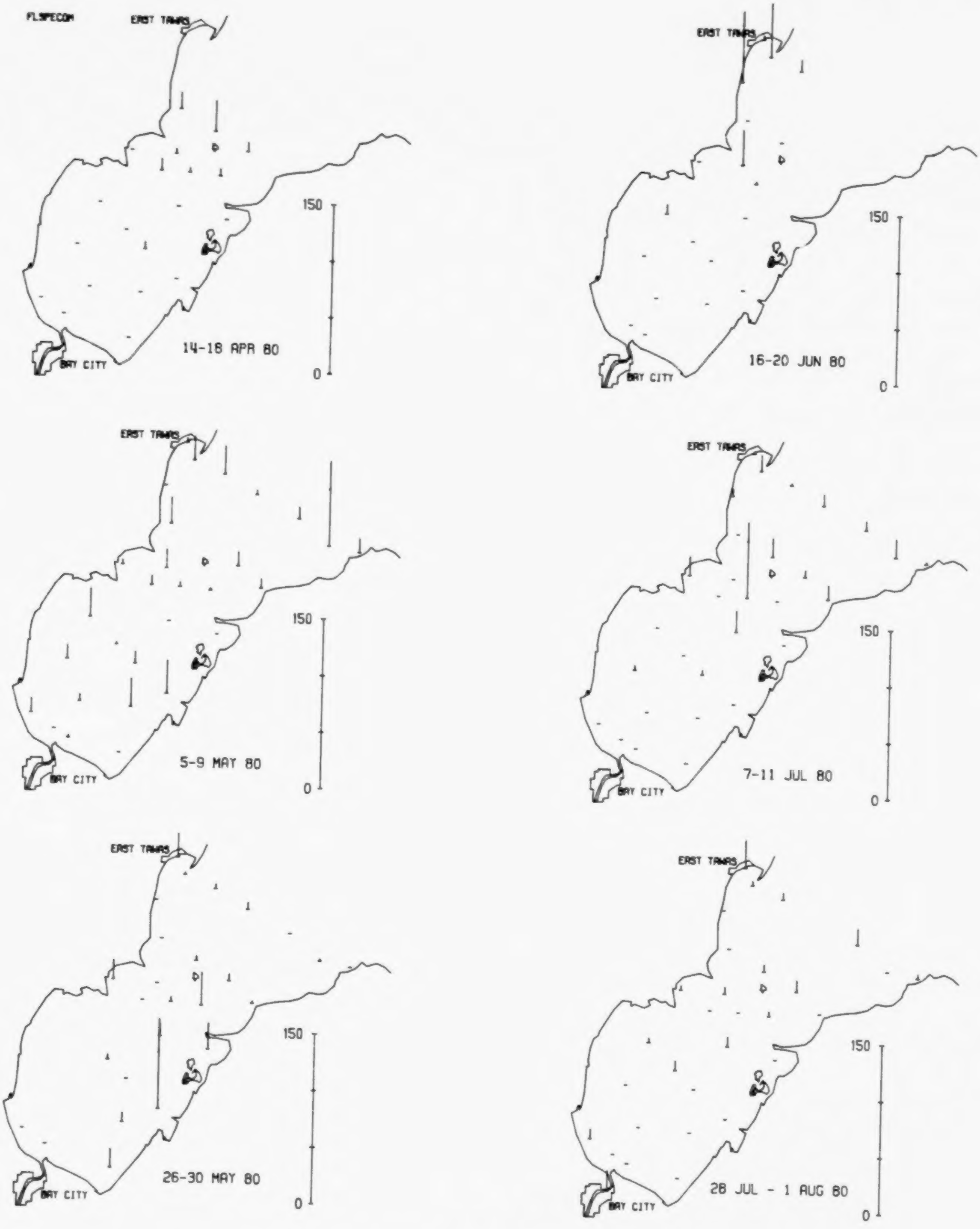

FLSPECOM
EAST TAWAS
BAY CITY
150
0
14-18 APR 80
16-20 JUN 80
5-9 MAY 80
7-11 JUL 80
26-30 MAY 80
28 JUL - 1 AUG 80

Figure 55. Distribution of flagellate species #13.

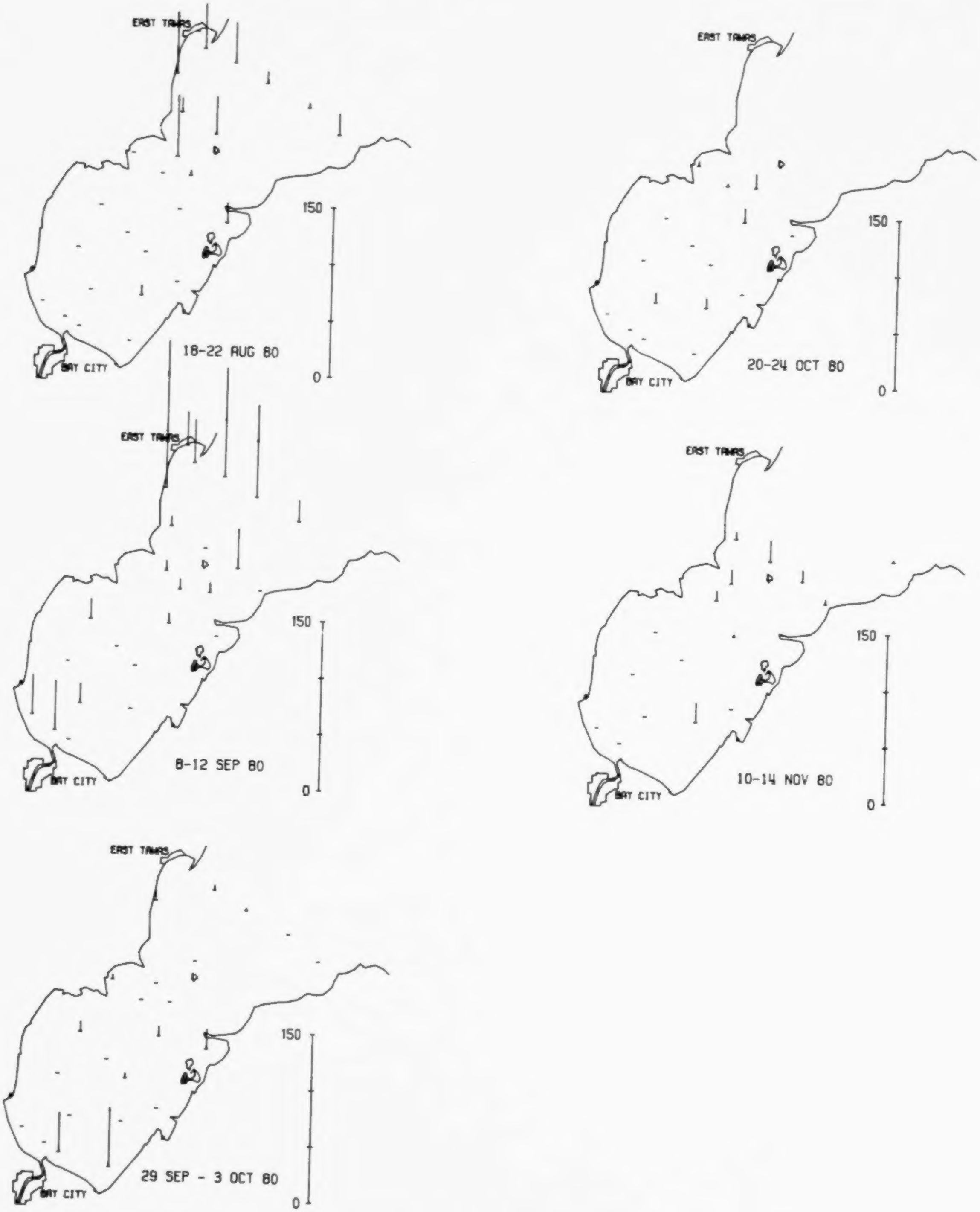

EAST TAWAS
BAY CITY
150
0
18-22 AUG 80
20-24 OCT 80
8-12 SEP 80
10-14 NOV 80
29 SEP - 3 OCT 80

Figure 55. (continued).

Pyrrhophyta or dinoflagellates (Figure 56)

Although the dinoflagellates are relatively rare in the Great Lakes, they may constitute a significant portion of the biomass because of their large size. Ecological affinities of many freshwater species are poorly known. As a group, dinoflagellates are common but not abundant throughout the Bay. Seasonal and spatial distribution is relatively uniform although there is a tendency for higher densities nearshore in the eastern Bay.

Euglenophyta (Figure 57)

This division reaches its greatest abundance and diversity in waters high in organic carbon. Representatives of this division are very rarely reported from the Great Lakes and never in abundance. Sporadic occurrences of very low cell densities in the inner Bay characterize this division's distribution in Saginaw Bay.

Community Analysis

This part of this report examines spatial and seasonal distributions of more or less well defined phytoplankton communities. Two multivariate statistical methods, principal components analysis (PCA), and cluster analysis (see Sneath and Sokal 1973), were used to identify taxa whose distributions were closely associated with one another. Cluster analysis illustrates well in graphic form the multivariate relationships of stations or samples that are highly similar. Complete linkage was the clustering strategy applied to the Euclidean distances among stations or samples. Principal components analysis

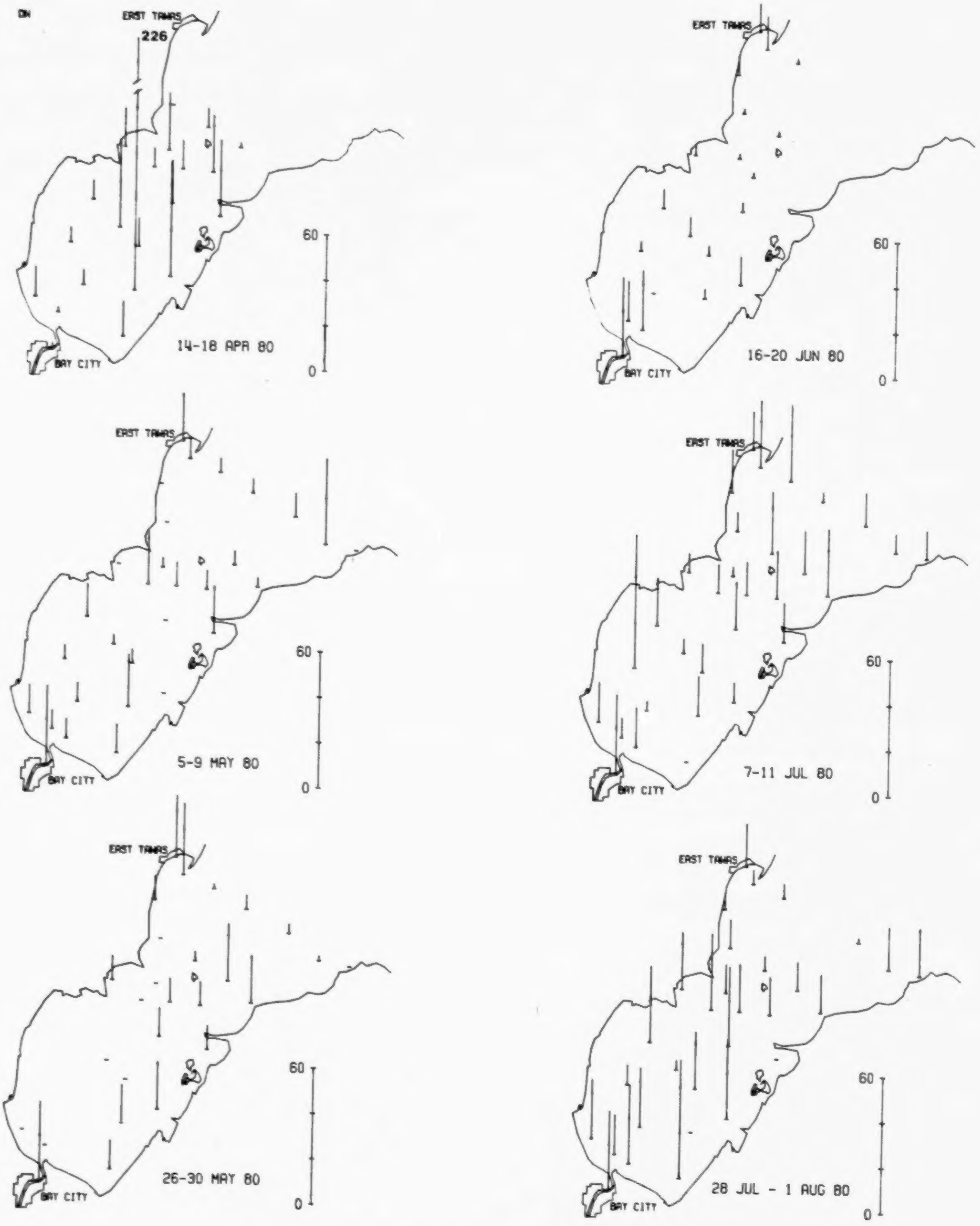

DN
EAST TAWAS
226
BAY CITY
60
0
14-18 APR 80
16-20 JUN 80
5-9 MAY 80
7-11 JUL 80
26-30 MAY 80
28 JUL - 1 AUG 80

Figure 56. Distribution of dinoflagellates.

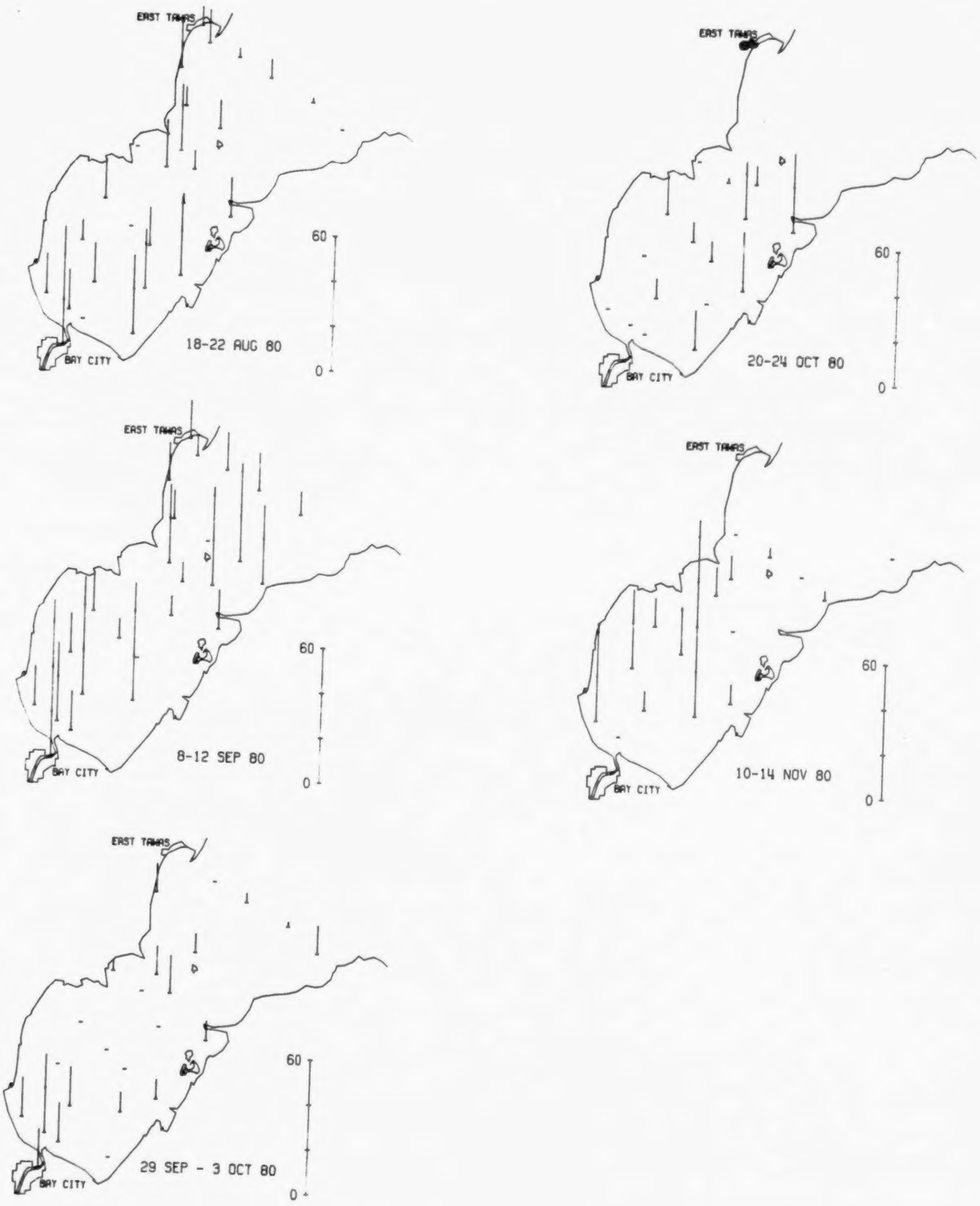

EAST TAWAS
BAY CITY
18-22 AUG 80
60
0
EAST TAWAS
BAY CITY
20-24 OCT 80
60
0
EAST TAWAS
BAY CITY
8-12 SEP 80
60
0
EAST TAWAS
BAY CITY
10-14 NOV 80
60
0
EAST TAWAS
BAY CITY
29 SEP - 3 OCT 80
60
0

Figure 56. (continued).

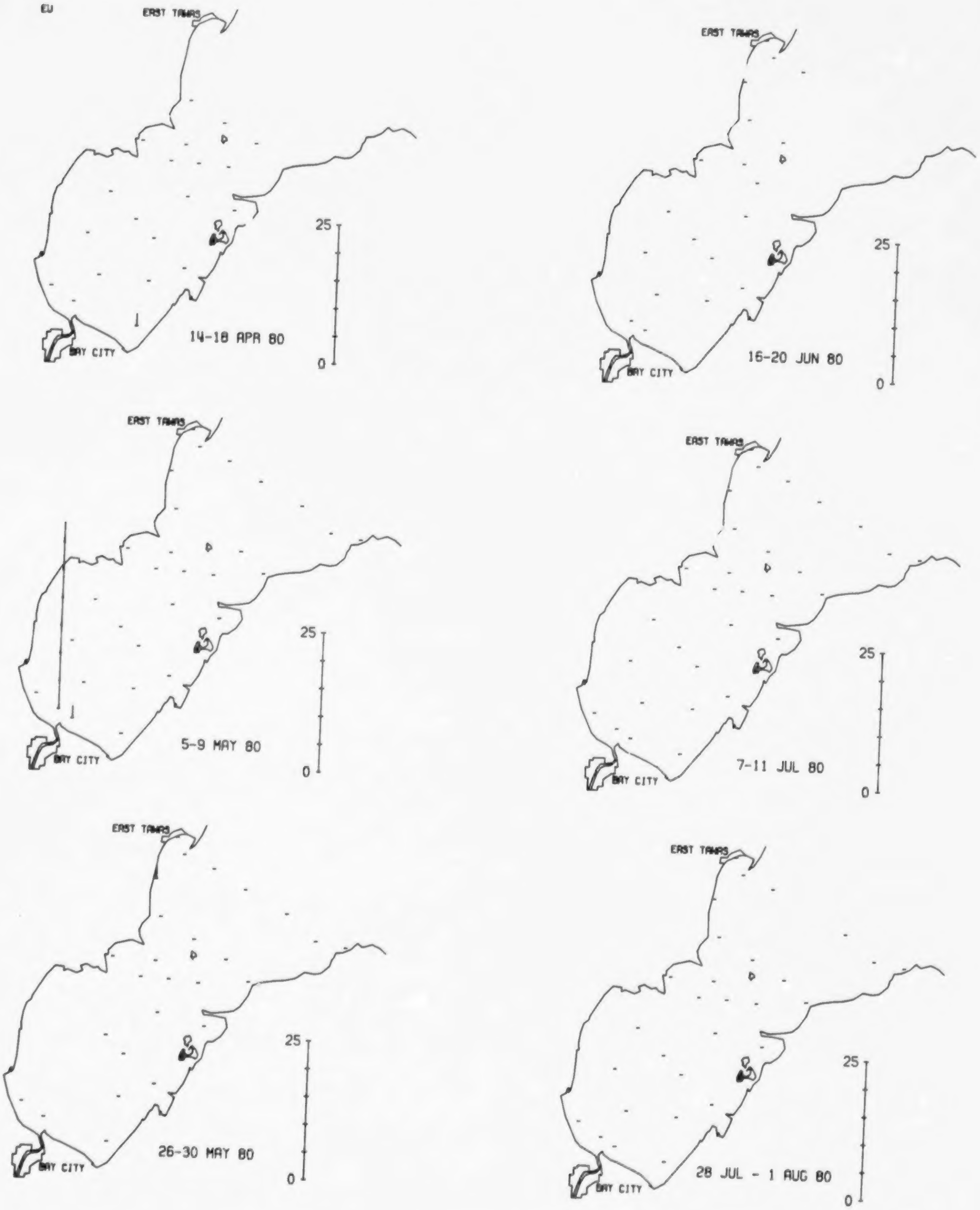

EU
EAST TAWAS
BAY CITY
14-18 APR 80
25
0
EAST TAWAS
BAY CITY
16-20 JUN 80
25
0
EAST TAWAS
BAY CITY
5-9 MAY 80
25
0
EAST TAWAS
BAY CITY
7-11 JUL 80
25
0
EAST TAWAS
BAY CITY
26-30 MAY 80
25
0
EAST TAWAS
BAY CITY
28 JUL - 1 AUG 80
25
0

Figure 57. Distribution of euglenophytes.

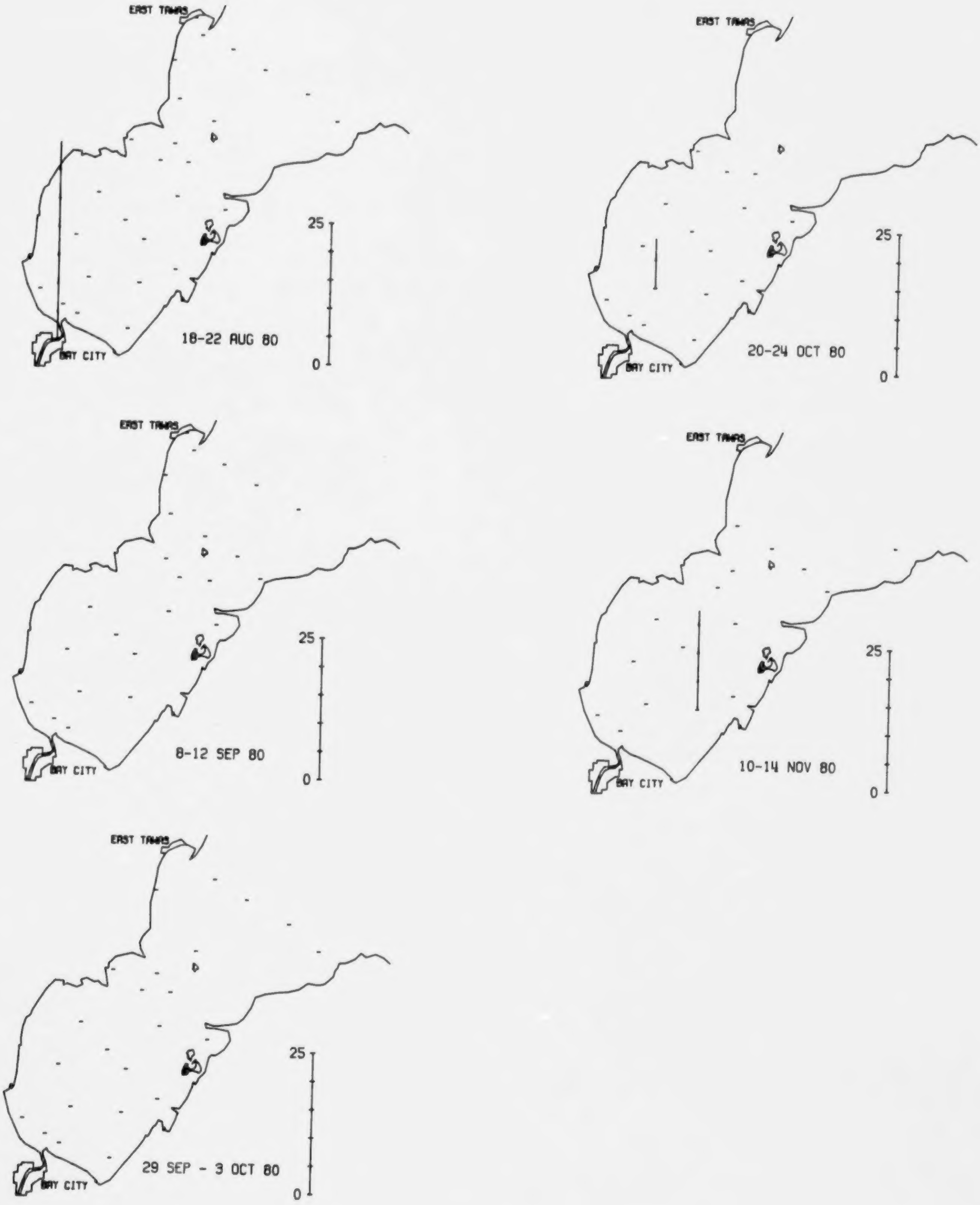

EAST TAWAS
BAY CITY
18-22 AUG 80
25
0
EAST TAWAS
BAY CITY
20-24 OCT 80
25
0
EAST TAWAS
BAY CITY
8-12 SEP 80
25
0
EAST TAWAS
BAY CITY
10-14 NOV 80
25
0
EAST TAWAS
BAY CITY
29 SEP - 3 OCT 80
25
0

Figure 57. (continued).

illustrates and explains the relationships and differences among phytoplankton associations previously defined by cluster analysis. Principal components analysis (PCA) was performed on the matrix of correlation coefficients of selected taxa. Over 500 taxonomic entities were recorded in this study, at various taxonomic levels. Even with computer-aided analyses, this is an unwieldly collection of variables. Before a taxon was included in multivariate analysis, it had to meet two criteria: that it be well defined taxonomically, i.e. at the genus level or lower; and, that it was among the twenty most abundant taxa on at least one cruise. Fifty-seven taxa met these criteria (Table 5).

Average Bay-wide Community Analysis

For this analysis, the mean of each species was calculated for each station over all cruises. This effectively integrated the seasonal component of variation and allowed better recognition of average spatial relationships. All 57 taxa listed in Table 5 were used in this analysis.

Stations were divided in two two major regions based on the phytoplankton community associations (Figure 58). Region A was a loose association of stations at or near the mouth of the Saginaw River. This region could be identified via both cluster analysis and PCA (Figures 59, 60, and 61). Region B consisted of 3 subgroups (Figure 58) which could be identified by cluster analysis (Figure 59). Figures 60 and 61 illustrate that these subgroups merge one into the other in a sequence which reflects their geographical relationships (Figure 58). Two stations, Stations 34 and 54 (Wild Fowl Bay and the station at Bay City), are distinct from all other stations (Figures 59, 60 and 61). Station 44, Oak Point, may be thought of as intermediate to

TABLE 5. RESULTS OF PRINCIPAL COMPONENTS ANALYSIS FOR AVERAGE BAY-WIDE COMMUNITY ASSOCIATION STUDY

		FACTOR LOADINGS	
	PC I	PC II	PC III
Taxon % variance	36.8	18.4	10.8
Anabaena flos-aquae	.02416	.04175	.05618
Asterionella formosa	.01208	.01907	-.05515
Anacystis cyanea	.20020	-.01386	.09893
A. incerta	.16228	-.15727	.02471
Aphanizomenon gracile	.13827	-.21229	.00065
Blue-green filament #3	.07591	-.26259	-.09095
Blue-green filament #4	.08493	-.27353	-.07891
Chodatella quadriseta	.11442	-.06891	.09731
Coelastrum microporum	.18758	.08575	.09353
Coelastrum spp.	-.01195	.02225	.03705
Cryptomonas spp.	.14322	.15967	-.10597
Cyclotella comensis	-.05052	-.21339	.07133
C. meneghiniana	.05985	.11612	-.34136
C. pseudostelligera	.06974	.12199	-.32877
Dictyosphaerium ehrenbergianum	.16291	.10633	.03436
Diatoma tenue var. *elongatum*	.15271	.02394	.11389
Dinobryon spp.	-.00261	-.04430	.11615
Flagellate #10	.23038	-.17326	-.07452
Fragilaria capucina	.10738	.10233	.18021
F. crotonensis	.10705	.01069	.18762
F. pinnata	.11174	-.24221	-.05392
Gloeocystis planctonica	.17107	.10863	.09010
Gloeocystis spp.	.10845	.10173	-.08966
Gomphosphaeria lacustris	.18017	-.00002	.13241
G. wichurae	.12501	.05673	.10163
Gloeotila pelagica	.14572	-.20429	-.03024
Gloeotila spp.	.06489	-.20681	-.02627
Chroomonas spp.	.15656	.05465	-.14713
Kirchneriella spp.	.15328	.08898	.12582
Microcoleus vaginatus	-.05758	-.02264	-.00434
Melosira granulata	.12199	.16047	-.08318
Mougeotia spp.	.12637	-.24264	-.02611
Nitzshia spp.	.14732	-.02437	-.22765
Ochromonas spp.	.11670	.00755	.15279
Oocystis spp.	.17277	.02307	.15309
Oscillatoria limnetica	.09074	-.25146	-.14213
O. retzii	.12429	.11688	-.24555
Oscillatoria spp.	.07176	.08476	-.29711
Pediastrum boryanum	.17417	.03842	.07107

(continued)

TABLE 5. (continued).

Taxon	% variance	FACTOR LOADINGS PC I 36.8	FACTOR LOADINGS PC II 18.4	FACTOR LOADINGS PC III 10.8
Pelonema sp.		.09450	-.26079	-.07314
Porphyrosiphon sp.		.13691	-.05083	-.15433
Rhodomonas minuta		.05836	.11504	.09792
Scenedesmus acuminatus		.19940	.05815	-.08842
S. acutiformis		.17954	.02400	.15380
S. armatus var. *boglariensis*		.18023	.06300	.04192
S. carinatus		.17193	.05331	.07916
S. decorus var. *bicaudato-granulatus*		.19904	.01820	.10051
S. quadricauda		.20088	.04706	-.00878
S. spinosus		.19988	.01268	.04788
Scenedesmus spp.		.20689	.00986	.01359
Stephanodiscus binderanus		.04643	.04626	.16890
S. hantzschii		.12858	.08257	.11475
S. subtilis		.12119	.14834	-.25658
S. tenuis		.14380	.14412	-.16188
Synedra filiformis		.08321	-.26634	-.06568
Tabellaria flocculosa var. *linearis*		-.04923	-.04022	.12684
Fragilaria construens		.15043	-.21139	-.04348

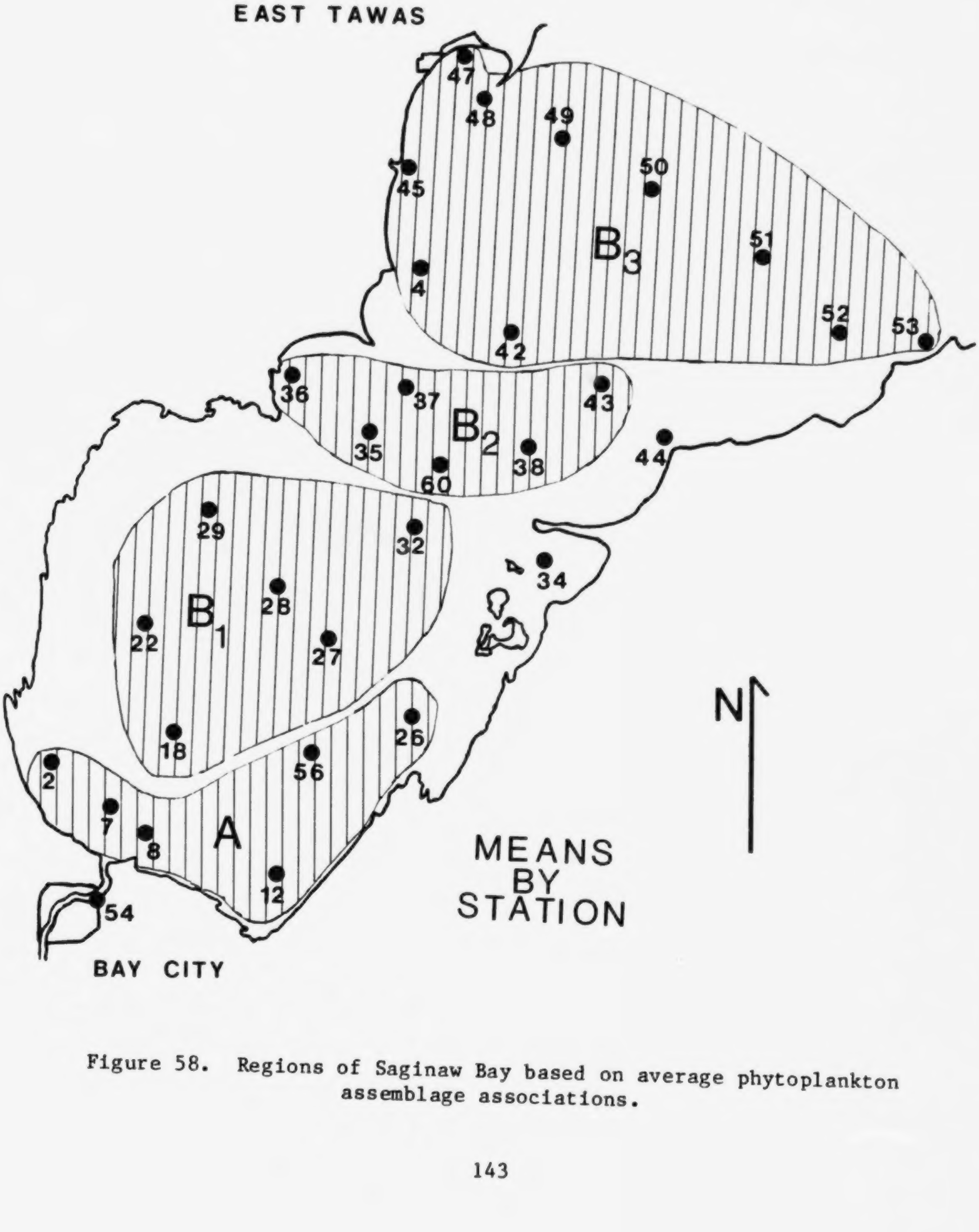

EAST TAWAS
47
48
49
45
50
B3
51
4
52
53
42
36
37
43
B2
35
60
38
44
29
32
34
B1
28
22
27
N
18
26
2
56
7
8
A
MEANS BY STATION
12
54
BAY CITY

Figure 58. Regions of Saginaw Bay based on average phytoplankton assemblage associations.

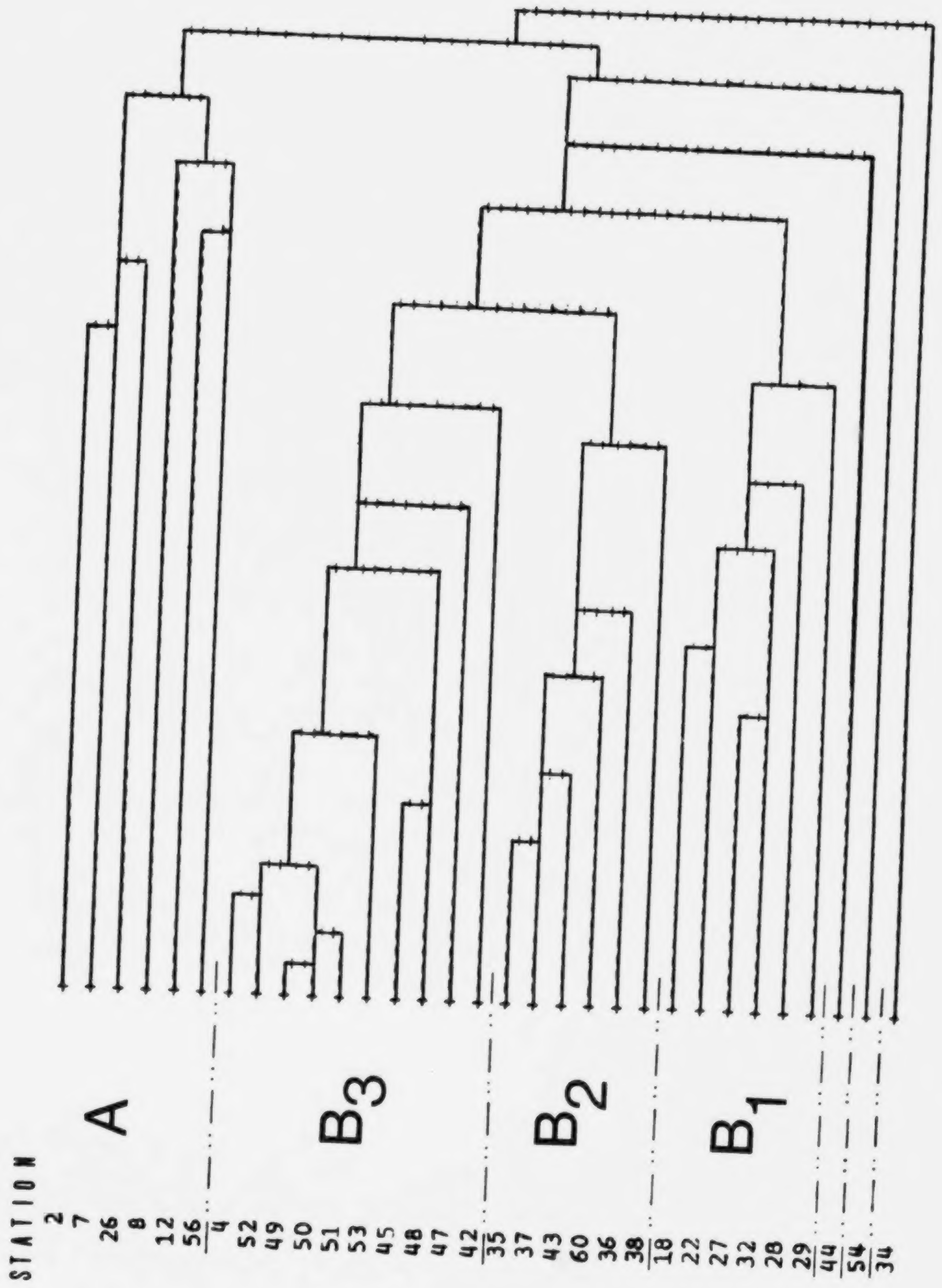


Figure 59. Cluster analysis of average bay phytoplankton communities.

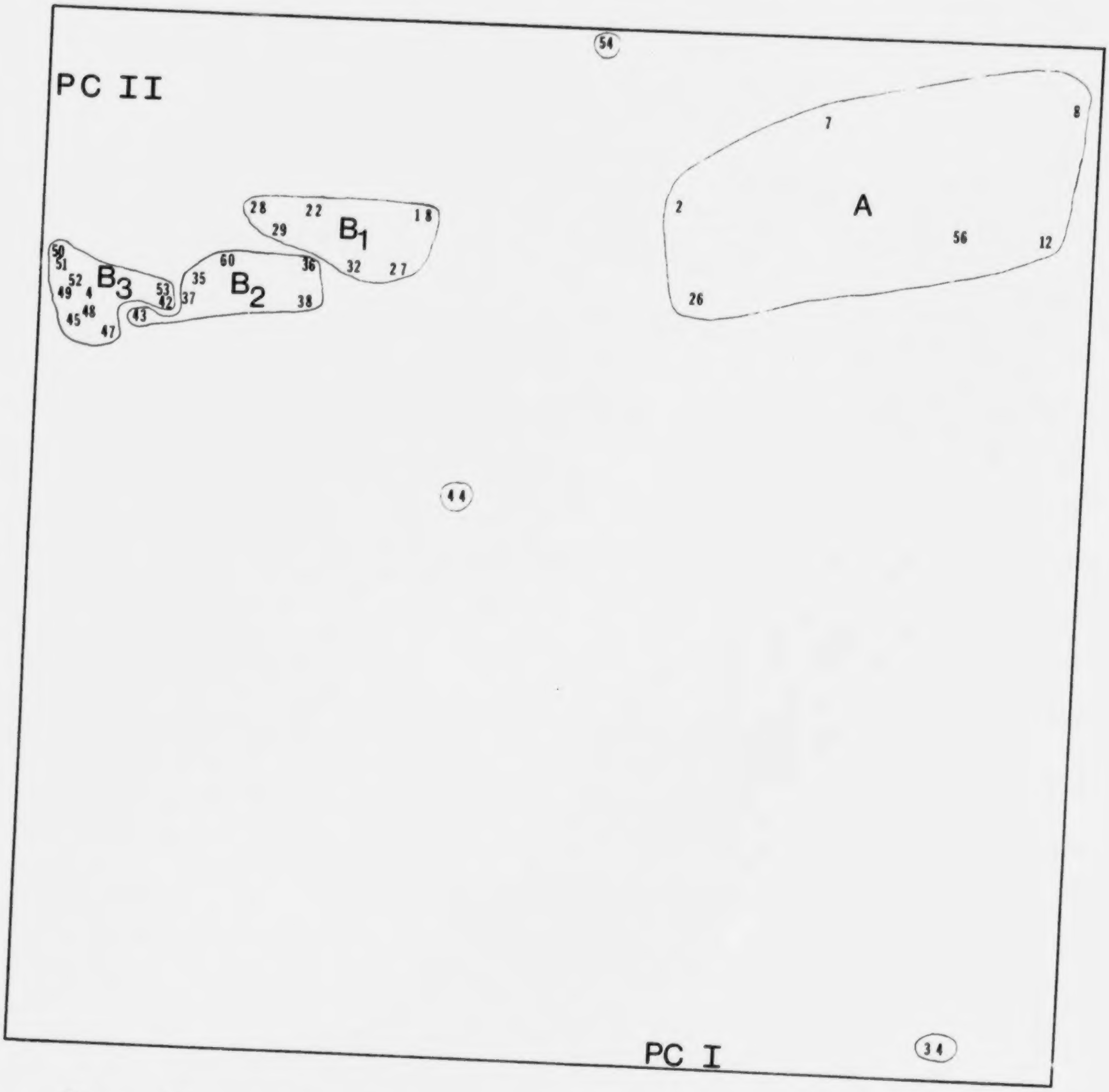


Figure 60. Principal components analysis of average Bay phytoplankton communities. Scatter plot of Saginaw Bay stations on PCI and PCII.

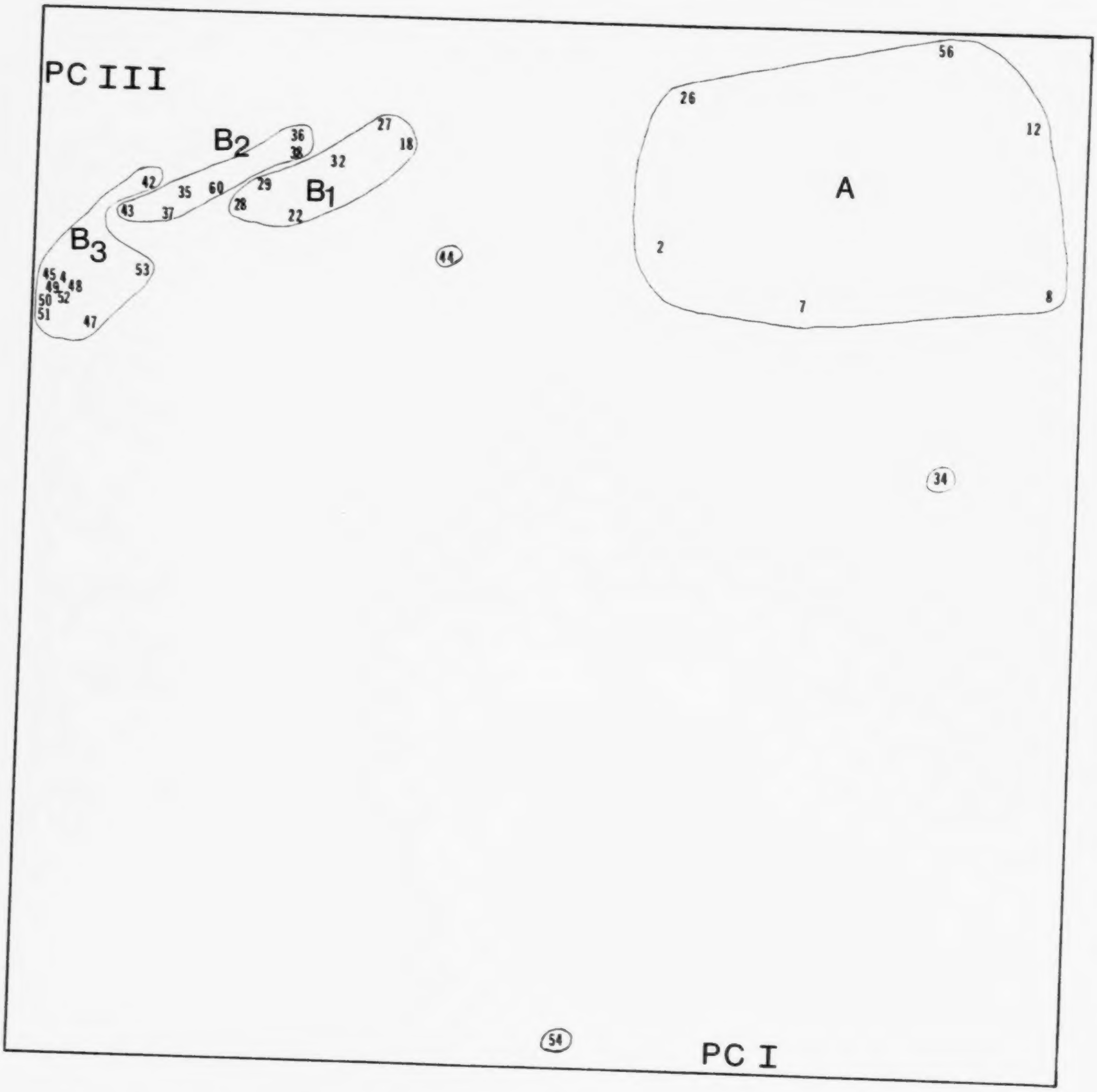


Figure 61. Principal components analysis of average Bay phytoplankton communities. Scatter plot of Saginaw Bay stations on PCI and PCII.

regions A and B in community structure and abundance (Figures 60 and 61), although it is only loosely associated with either.

Species loading on principal components axes (PC axes) give some insight into differences among station groupings based on phytoplankton associations. Loadings on PC I are nearly equal and all are near zero or strongly positive (Table 5). Thus, the major average differences among stations are not in kinds of species but in levels of phytoplankton abundance. That is, stations to the right of Figures 60 and 61 tend strongly to have higher abundance levels than stations on the left. However, qualitative information makes finer distinctions among stations and regions than purely quantitative data.

Separation of Wild Fowl Bay and Oak Point from each other and from the rest of the stations occurs on PC II (Figure 60). With the exception of _Synedra filiformis_, species heavily loaded on this axis (arbitrarily, loading factors > 0.25; Table 5), are all blue-green filaments. Individual species plots previously showed that high abundances of these filaments and _S. filiformis_ were characteristic of Wild Fowl Bay and Oak Point. PC III separates station 54 from all other stations (Figure 61). Species heavily loaded on PC III (arbitrarily, loading factors >0.25; Table 5) are mainly diatom species with distinct riverine distribution (Table 5, and individual species plots).

Region A was characterized by _Gloeotila_ spp., _Rhodomonas minuta_, certain riverine diatoms, namely _Cyclotella meneghiniana_, _Melosira granulata_, _Skeletonema costatum_ and _Thalassiosira_ spp. and by the blue-green filaments _Aphanizomenon gracile_, blue-green filament #4, _Oscillatoria limnetica_, _Pelonema_ sp. and _Porphyrosiphon_ sp. Also characteristic of A was the diatom _Synedra filiformis_, which was again found in association with several blue-green filaments, although these were not the same blue-green species with which it was associated at Wild Fowl Bay.

Three subregions were identified in Region B. Region B_1 is characterized by high abundances of the blue-green algal *Oscillatoria retzii*, several green algae including *Scenedesmus carina*, *S. spinosus* and *Coelastrum microporum*, the cryptomonads *Rhodomonas minuta* and *Cryptomonas* spp., and the diatom *Stephanodiscus subtilis*. Species loadings and individual species plots indicate that Region B_2 has a mesotrophic character relative to B_1, and that high abundances of the cryptomonad *Chroomonas* spp., and the eurytopic diatoms *Nitzschia* spp., *Tabellaria flocculosa* var. *linearis*, *Asterionella formosa*, *Cyclotella comensis* and *Synedra filiformis* characterize region B_2. Species factor loadings indicate that none of the dominant species are strongly associated with region B_3. However, individual species plots show that several species characteristic of the open waters of Lake Huron have Saginaw Bay distributions generally restricted to, or reach their greatest abundance at, stations in B_3. These species include the diatoms *Melosira islandica*, *M. italica*, *Cyclotella ocellata* and *C. comta*, the chrysophyean alga *Spiniferomonas* sp., and flagellate species #13.

In summary, the river area in the inner Bay, i.e. Region A and station 54, was characterized by diatom species which reach their highest abundances in the River proper, as well as many blue-green filaments which are indicative of highly eutrophic conditions. The floristic elements associated with region B indicate a transition across a broad front from the inner Bay to the outer Bay stations. Only a few distinctly riverine taxa or taxa indicative of severely disturbed habitats (in particular, *Stephanodiscus subtilis* and *Oscillatoria retzii*) are numerically important in B. A more mesotrophic flora consisting mainly of eurytopic diatoms is characteristic of region B_2. Total phytoplankton abundances are also lower in B_2 than in B_1. Total abundances are lowest of all in B_3 and this region is characterized by diatoms and flagellates associated with oligotrophic conditions. Thus, on the average, all stations at the Bay-Lake Huron interface are more like one another, both in kinds of species and in cell densities than they are like stations in the middle Bay. Wild Fowl Bay and Oak Point are characterized by exceptionally high abundances of blue-green filament species. The distribution of several of these species is restricted to Wild Fowl Bay and the immediate area. The high standing crops of species unique to Wild Fowl Bay, and to a lesser extent, Oak Point, suggests that these areas may not be well integrated with the rest of the Bay.

Community analysis by cruise

For this part of the analysis, phytoplankton assemblages were identified by cruise with multivariate analyses on the 20 most abundant taxa for that cruise.

Cruise 83, April 14-18 (Figure 62)

Saginaw Bay could be divided into three regions. Region A consisted of stations at or near the Saginaw River. Characteristic of this region were several taxa with eutrophic water affinities and others generally limited to the River, including Gloecystis spp., Scenedesmus spp., Stephanodiscus subtilis and S. hantschii. Region B was a loose association of four stations characterized by the eurytopic diatoms Fragilaria crotonensis, F. pinnata and F. capucina, and the blue-green alga Gomphosphaeria lacustris. Region C was a

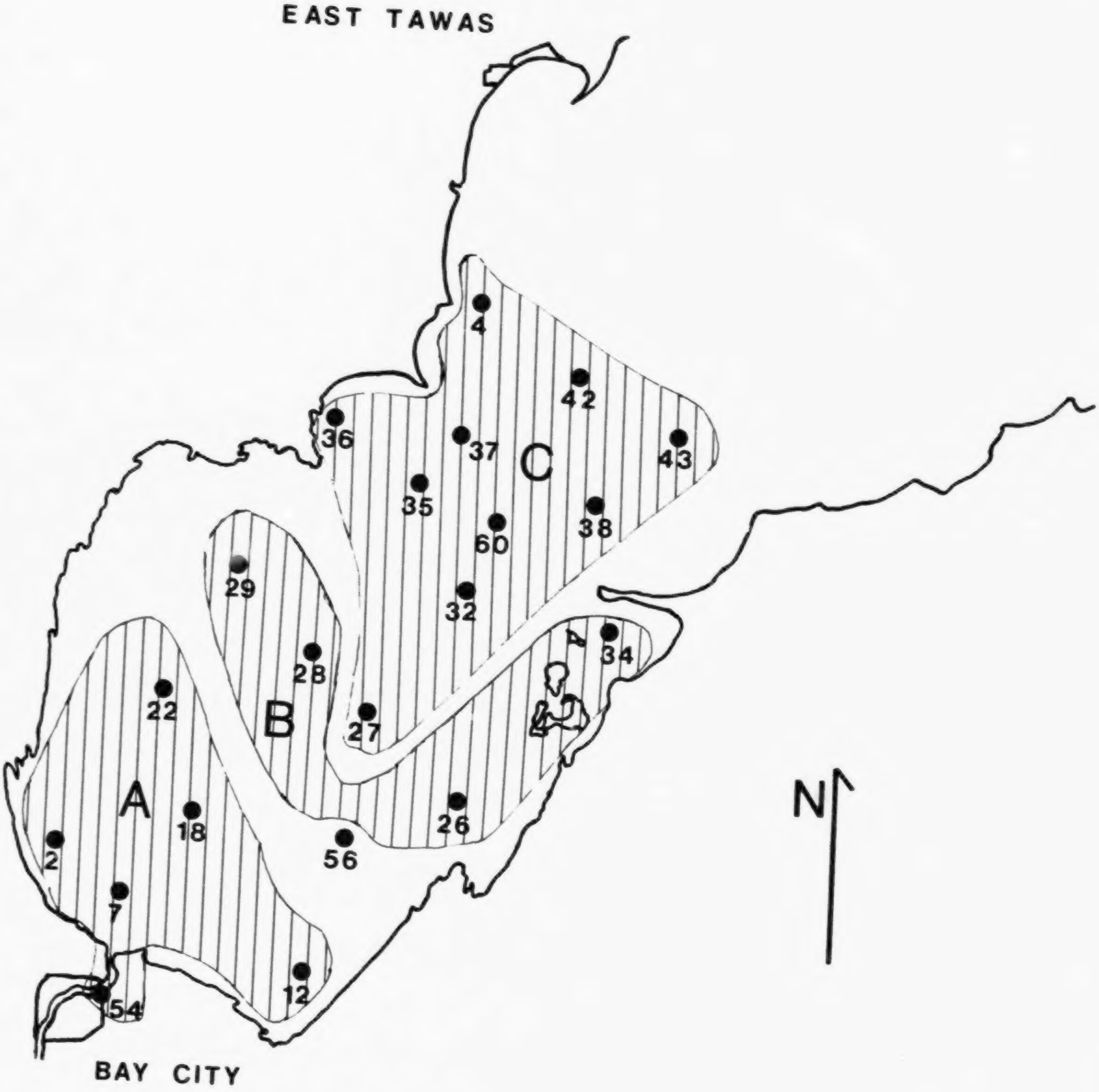

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Figure 62. Regions of Saginaw Bay during cruise 83.

tight association of stations characterized by the flagellates *Ochromonas* spp. and *Chroomonas* spp., and the diatom *Cyclotella comensis*. Station 56 was not associated with any region. Abundance levels of most all species were very high at this station, but especially abundant at this station were *Anacystis incerta*, *Asterionella formosa*, *Diatoma tenue* var. *elongatum*, *Stephanodiscus hantzschii* and *Synedra filiformis*.

Cruise 84, May 5-9 (Figure 63)

Station clusters were not as well defined on this cruise. Most of the middle and inner Bay stations formed a loose cluster (Region C) which was geographically and floristically central to several outlying regions. The river stations formed one endpoint (Region A), characterized primarily by the riverine diatoms *Cyclotella pseudostelligera*, *Stephanodiscus tenuis*, *Stephanodiscus subtilis* and *Diatoma tenue*, and secondarily by the eurytopic species *Asterionella formosa*, *Rhodomonas minuta* and *Chroomonas* spp. Region B represented the transition between riverine (A) and Region C stations, and was characterized by the riverine diatoms *Stephanodiscus tenuis*, *S. subtilis*, *Cyclotella pseudostelligera* and *Diatoma tenue* var. *elongatum*, and by *S. binderanus*, *Chroomonas* spp. and *Fragilaria capucina*. Region C could not be well characterized but contained floristic elements of all the surrounding regions. Region D represents the transition between C and E and was characterized by eurytopic algae such as *Fragilaria capucina*, *Cyclotella comensis* and *Chroomonas* spp., and by two diatoms characteristic of open Lake Huron waters, *Melosira islandica* and *Cyclotella ocellata*. Region E was

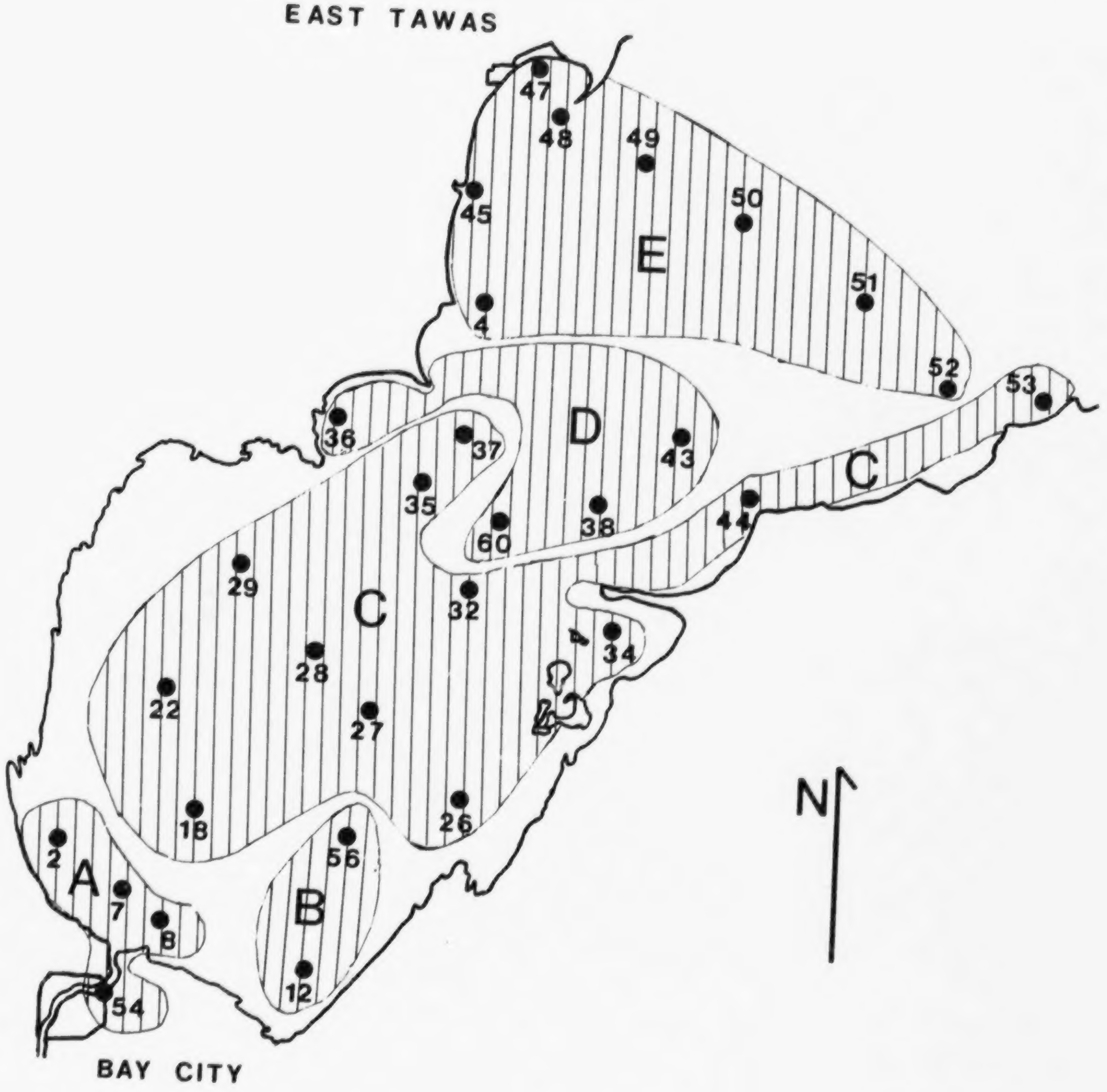
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Figure 63. Regions of Saginaw Bay during cruise 84.

characterized by *Cyclotella comensis*, *C. ocellata*, *C. stelligera*, *Melosira islandica* and relatively high levels of *Rhodomonas minuta*.

Cruise 86, May 26-30 (Figure 64)

Five assemblages were recognized. Region A was composed of three stations in and near the Saginaw River. Characteristic of this region were *Scenedesmus spinosus*, *S. quadricauda*, *S. armatus* var. *boglariensis*, *S. acuminatus*, *Gleocystis planctonica*, *Coelastrum microporum*, *Stephanodiscus tenuis* and *S. subtilis*. Region B was a loose association of inner Bay nearshore stations characterized by flagellate species #13, *Chroomonas* spp., *Scenedesmus quadricauda*, *Scenedesmus* spp., *Cryptomonas* spp. and *Pediastrum boryanum*. Region C was characterized by *Anabaena flos-aquae*, *Rhodomonas minuta* and *Fragilaria capucina*. Region D is intermediate geographically and floristicaly to Regions B and E. Characteristic of D are *Chroomonas* spp., flagellate #10, flagellate #13, *Ochromonas* spp., *Cyclotella comensis* and *Tabellaria flocculosa* var. *linearis*. Region E is characterized by *Cyclotella comensis*, *C. stelligera*, flagellate #13 and *Monochrysis aphanaster*.

Cruise 87, June 16-20 (Figure 65)

No samples were taken from Segment 5 on this cruise. Four regions could be identified from the rest of the Bay. Region A, composed of stations in and near the River, was characterized by *Stephanodiscus tenuis*, *Gleocystis planctonica*, *Scenedesmus* spp., *S. spinosus*, *S. quadricauda*, *Oscillatoria retzii* and *Anacystis incerta*. Region B was composed of inner Bay stations, forming a loose cluster characterized by *Rhodomonas minuta*, *Anabaena flos-aquae* and *Gomphosphaeria lacustris*. Region C was composed of stations in the

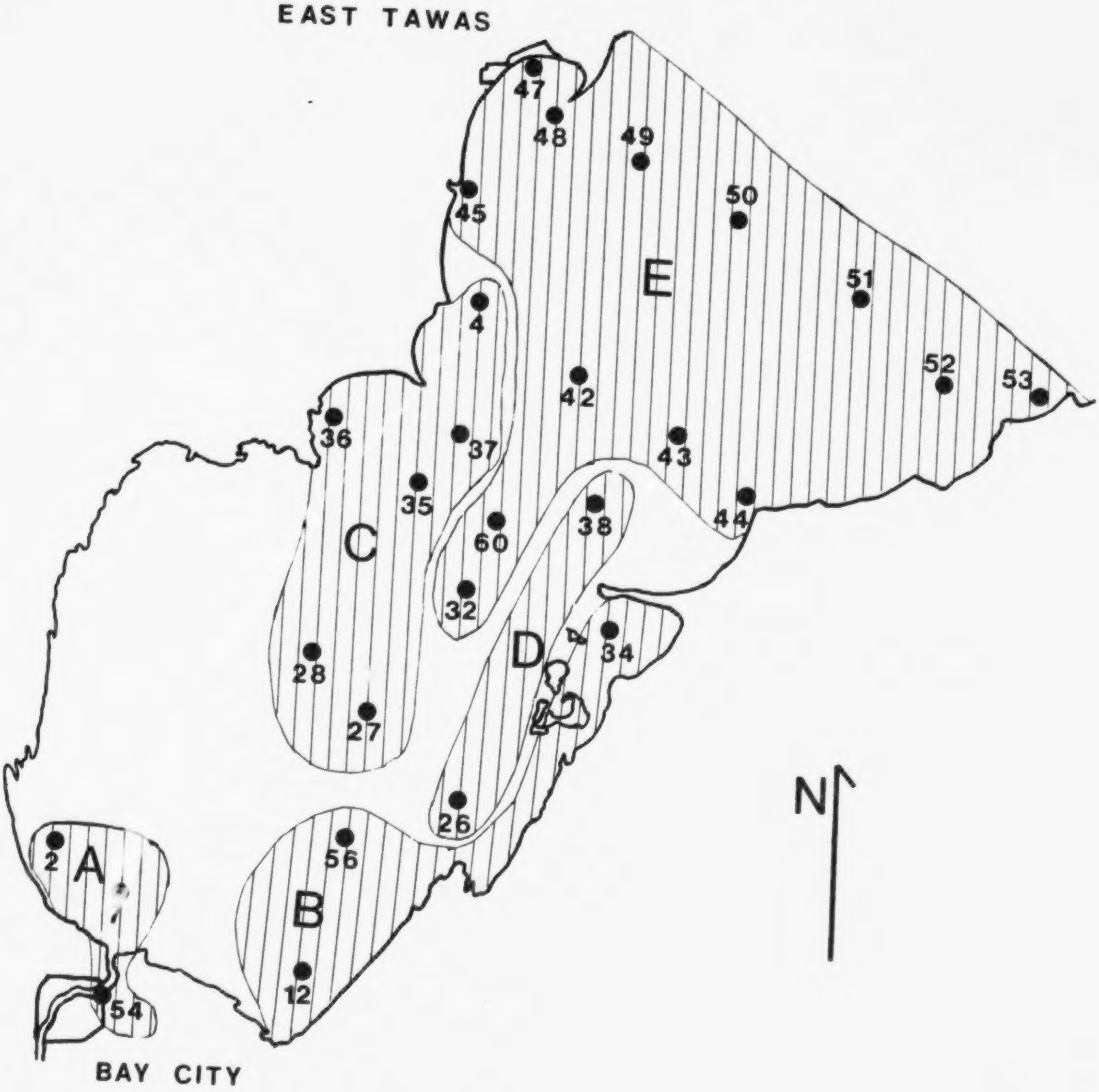
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Figure 64. Regions of Saginaw Bay during cruise 86.

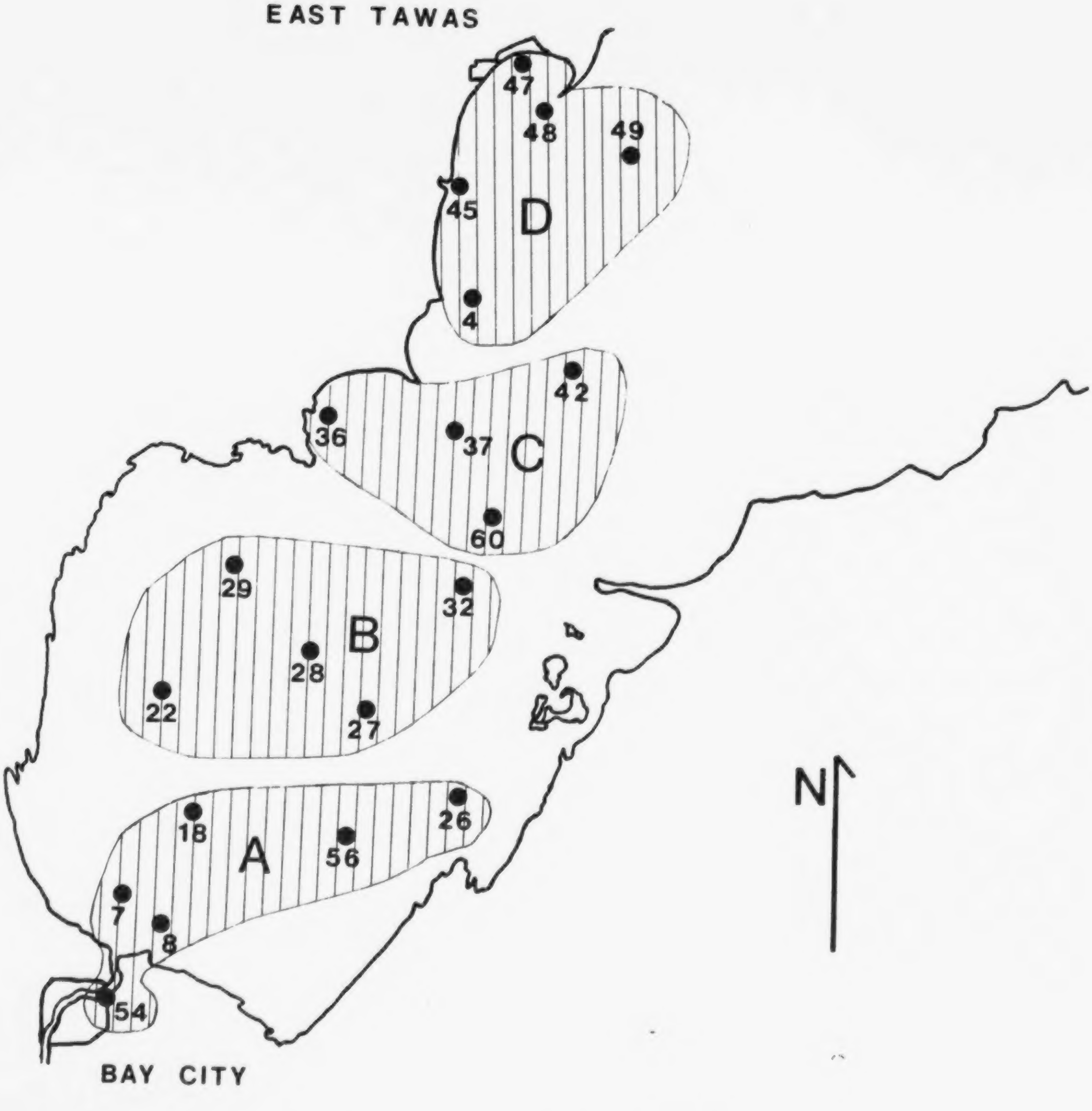
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Figure 65. Regions of Saginaw Bay during cruise 87.

middle Bay and characterized by *Monochrysis aphanaster*, *Mallomonas pseudocoronata*, flagellate #13, flagellate #10 and *Cyclotella stelligera*. Region D was characterized by *Cyclotella stelligera*, *C. ocellata* and *Microcolens vaginatus*.

Cruise 88, July 7-11 (Figure 66)

Segmentation of the Bay during this cruise indicates a possible strong influx of Lake Huron water into the Bay. Note that the outline of Regions C and D resembles the 8 m depth contour. Four regions were recognized. Region A is a loose association of stations characterized by *Oscillatoria retzii*, *Anacystis incerta*, *Gomphosphaeria lacustris*, *Coelastrum microporum*, *Scenedesmus acuminatus*, *S. quadricauda*, *S. acuminatus*, *S. carina*, *Cyclotella meneghiniana*, and *Melosira granulata*. Region B was characterized by *Anacystis cyanea*, *Scenedesmus spinosus*, *Fragilaria capucina* and *Cyclotella comensis*. Region C is a loose assemblage of stations characterized by high abundances of species typical of both regions B and D, including *Cyclotella comensis*, *Fragilaria crotonensis* and *Scenedesmus spinosus*. Relatively abundant in Region D were eurytopic taxa and taxa which frequently occurred at the Bay-Lake interface including *Fragilaria crotonensis*, *Cyclotella stelligera*, *Chrysococcus dokidophorus*, flagellate #10, flagellate #13 and *Dinobryon* spp.

Cruise 90, July 28-August 1 (Figure 67)

Three geographical regions could be identified in Saginaw Bay, and three stations represented separate point clusters which could not satisfactorily be placed in any region. Station 12 was characterized by generally high total phytoplankton abundances and specifically by high levels of *Anacystis cyanea*,

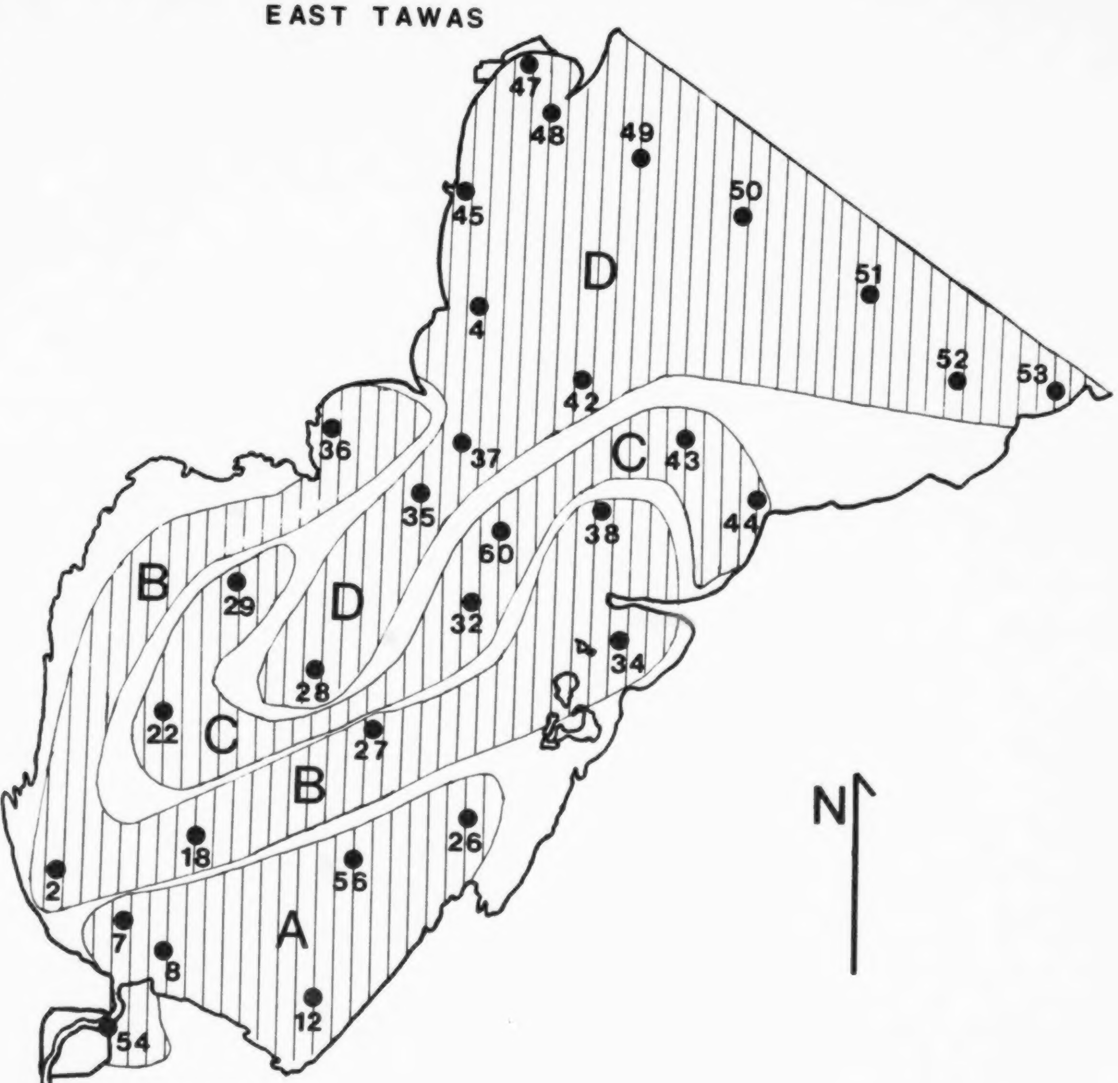
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Figure 66. Regions of Saginaw Bay during cruise 88.

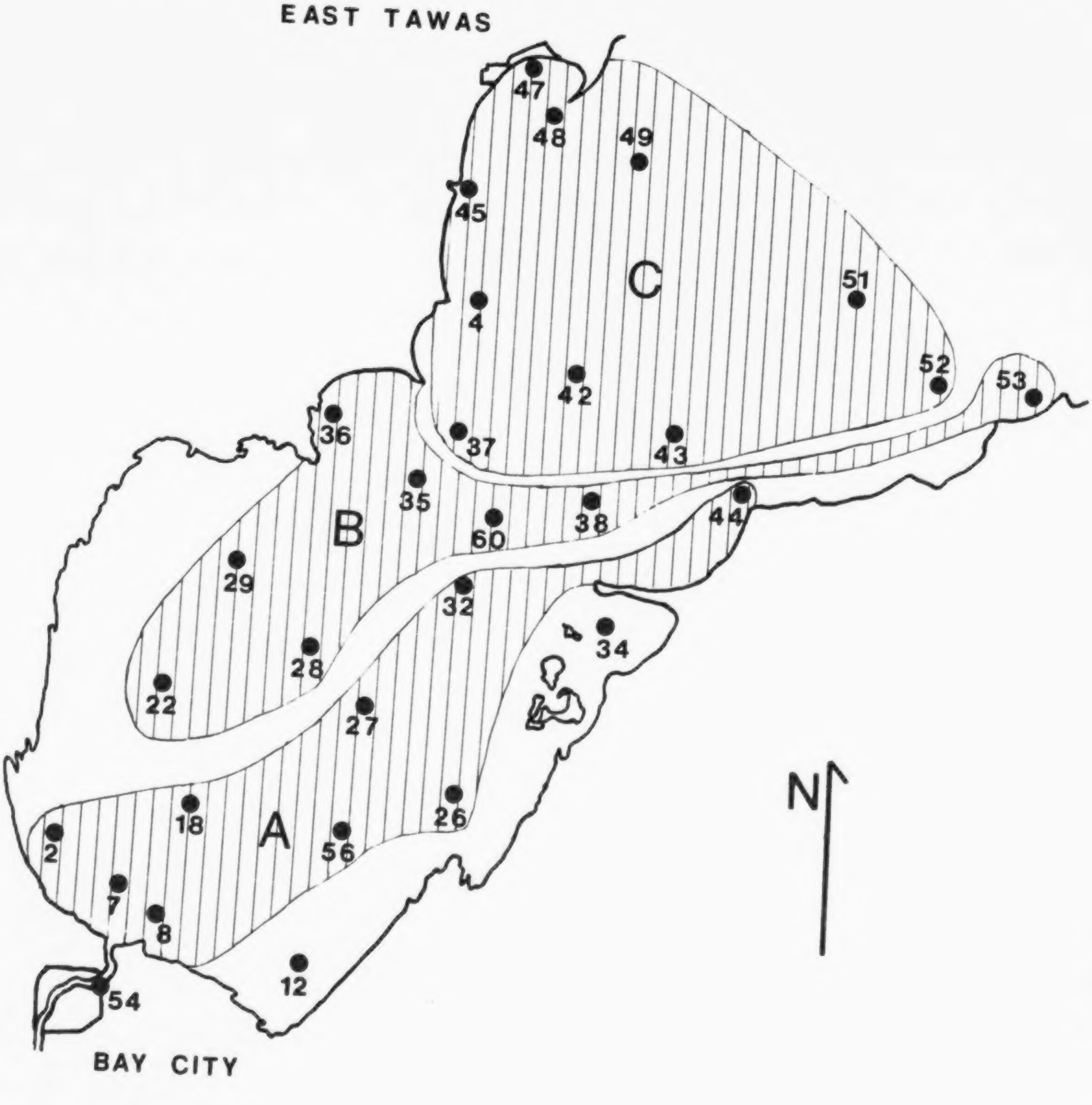
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Figure 67. Regions of Saginaw Bay during cruise 90.

Scenedesmus spp., *S. acuminatus*, *S. carina* and *Fragilaria crotonensis*. Station 34 was characterized by blue-green algae, especially *Anacystis incerta*, *Pelonema* sp. and *Aphanizomenon gracile*. Station 54 was characterized by moderate abundances of such riverine diatoms as *Skeletonema potamos*, *Cyclotella pseudostelligera* and *Stephanodiscus subtilis*, and by the blue-green filament *Schizothrix calcicola*. Region A was a loose cluster of stations characterized by *Fragilaria crotonensis*, *Anacystis incerta* and *Scenedesmus spinosus*. Region B was characterized by the eurytopic *Fragilaria crotonensis*, *Cyclotella comensis*, *Rhizosolenia eriensis*, and the oligotrophic indicators *Cyclotella comta* and *Monochrysis aphanaster*. The assemblage and abundance levels in this region suggest a mesotrophic water body. Region C was characterized by oligotrophic indicators *Cyclotella stelligera*, *C. comta* and *Chrysococcus dokidophorus*, and the eurytopic *C. comensis*.

Cruise 91, August 18-22 (Figure 68)

Four regions and a single point cluster were identified. Station 34 (Wild Fowl Bay) had a unique assemblage and could not be associated with any other station or stations. Wild Fowl Bay was characterized by high standing crops of blue-green filaments, especially *Pelonema* sp., *Oscillatoria limnetica*, blue-green filament #3, blue-green filament #4, *Schizothrix calcicola*, the green filament *Gloeotila pelagica*, and the diatom *Synedra filiformis*. Region A was composed of Saginaw River and near river stations and was characterized by *Cyclotella meneghiniana*, *Melosira granulata*, *Fragilaria capucina*, *Oscillatoria retzii*, *Scenedesmus spinosus*, *S. quadricauda* and *Pediastrum boryanum*. Region B was characterized by a mixture of blue-greens, eurytopic diatoms and greens, and so was intermediate floristically

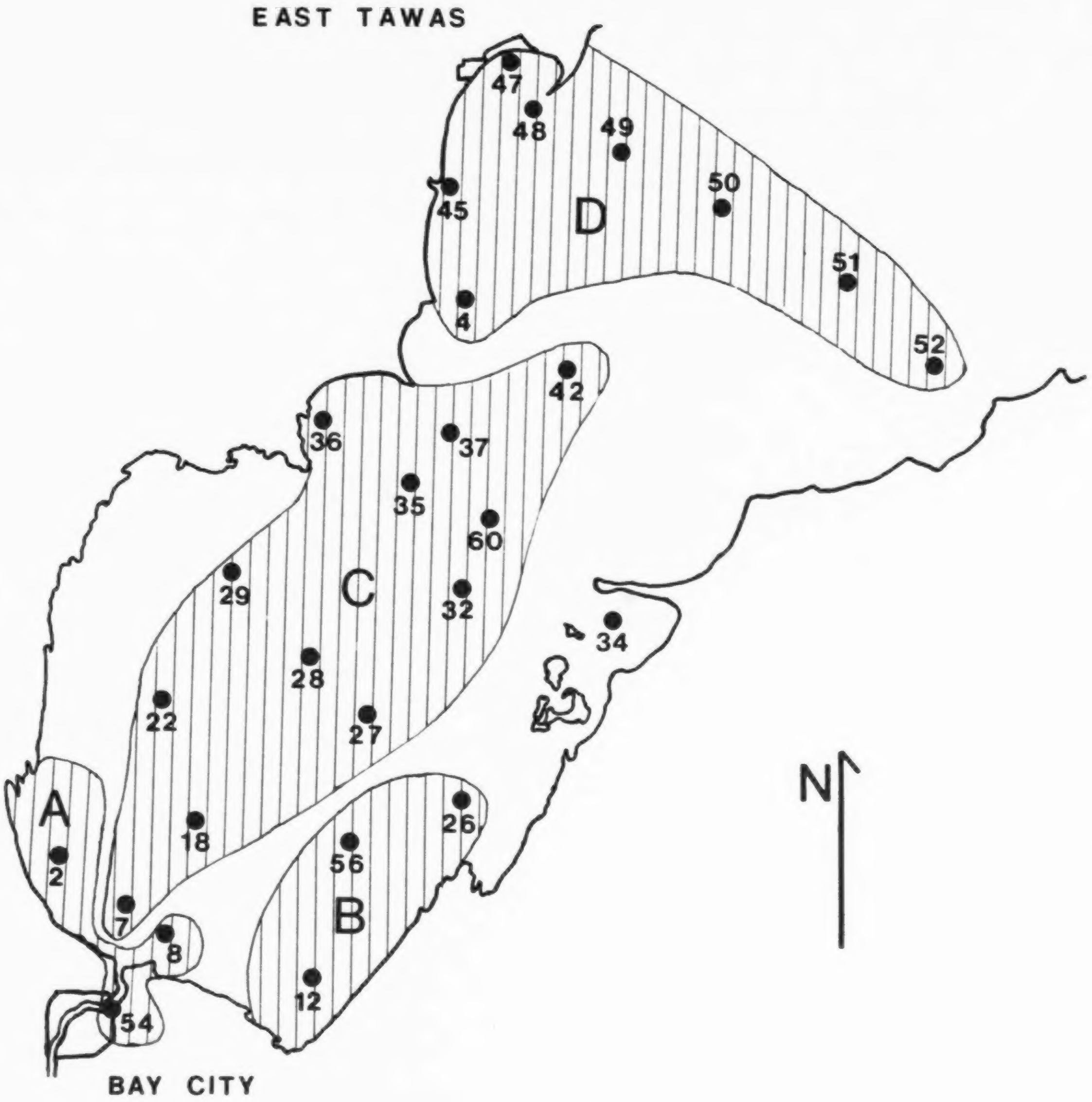
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Figure 68. Regions of Saginaw Bay during cruise 91.

between station 34 and regions A and C. The taxa included *Schizothrix calcicola*, *Gomphosphaeria wichurae*, *Anacystis cyanea*, *Pediastrum boryanum*, *Scenedesumus acutiformis*, *Fragilaria capucina* and *Cyclotella comensis*. Region C was characterized by a mixture of eutrophic, eurytopic and oligotrophic forms, including *Anacystis incerta*, *Coelastrum microporum*, *Fragilaria crotonensis*, *Cyclotella comensis*, *C. comta*, *C. stelligera*, flagellate #13 and *Ochromonas* spp. Region D was characterized by algae typical of the Bay-Lake interface, *Cyclotella stelligera*, *Cyclotella comta*, flagellate #10 and flagellate #13.

Cruise 92, September 8-12 (Figure 69)

When the Bay reached its maximum total phytoplankton abundance in early September, it simultaneously reached its apparent greatest diversity and divergence of apparent phytoplankton habitats in that four stations formed separate point clusters. Each of the eastern nearshore stations contained unique assemblages, very distinct from one another and from the open Bay. Even the stations in the inner and middle Bays were relatively distinct from one another. Nevertheless, they could be still identified as one loosely defined region (A) with little floristic similarity to a second region (B), or to the separate point regions. Station 34 was again characterized by blue-green filaments, as it was during most of the summer and early fall. Taxa important at Wild Fowl Bay were *Pelonema* sp., *Aphanizomenon gracile*, blue-green filament #3, blue-green filament #4, *Anacystis cyanea*, *Gloeotila pelagica* and *Synedra filiformis*. Station 44 had high abundances of *Gloeotila* spp., *Anacystis incerta*, *Anacystis cyanea* and *Mougeotia* spp. Station 54, in the Saginaw River, was characterized by the riverine diatoms *Cyclotella*

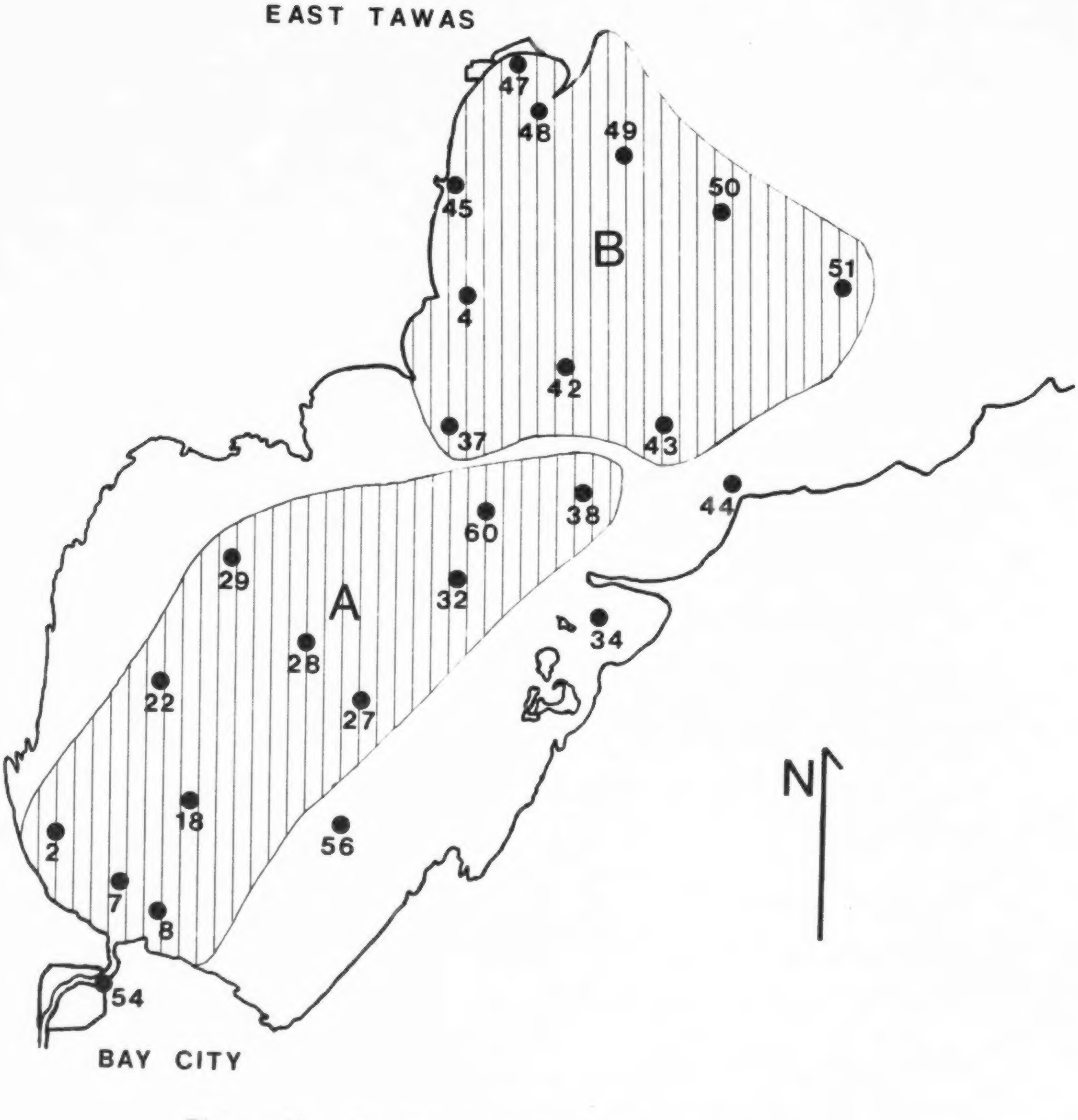
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Figure 69. Regions of Saginaw Bay during cruise 92.

meneghiniana, and *Skeletonema potamos*, and by *Oscillatoria retzii* and *Chroomonas* spp. Station 56, characterized by *Coelastrum microporum*, *Scenedesmus spinosus*, *Oocystis* spp., *Oscillatoria retzii* and *Melosira granulata*, was somewhat intermediate to station 54 and to Region A. Region A was characterized by *Fragilaria capucina*, *F. crotonensis*, *Cyclotella comensis*, *Melosira granulata*, *Rhodomonas minuta*, *Ochromonas* spp., *Scenedesmus acutiformis* and *S. spinosus*. Region B was characterized by *Cyclotella stelligera*, *C. comta*, *C. comensis*, *Fragilaria crotonensis*, flagellate #10, flagellate #13 and *Monochrysis aphanaster*, all species typical of the Bay-Lake interface.

Cruise 93, September 29-October 3 (Figure 70)

Four regions could be identified during this cruise. Region A was a loose association of stations in and near the River, characterized by *Oscillatoria retzii*, *Cyclotella meneghiniana*, *Melosira granulata*, *Fragilaria capucina*, *Scenedesmus quadricauda*, *S. decorus* var. *bicaudato-granulatus*, *S. acuminatus* and *Chroomonas* spp. Region B was composed of eastern inner Bay stations and characterized by several blue-green algae and green algae, including *Pelonema* sp., *Aphanizamenon gracile*, *Anacystis incerta*, *A. cyanea*, blue-green filament #4, *Scenedesmus acutiformis*, *S. spinosus*, and by eurytopic species such as *Fragilaria crotonensis* and *Rhodomonas minuta*. Region C was characterized by *Cyclotella comensis*, *Melosira granulata*, *Fragilaria capucina*, *Rhodomonas minuta* and *Scenedesmus acutiformis*. Region D was characterized by eurytopic and oligotrophic species such as *Fragilaria crotonensis*, *Cyclotella comensis*, *C. stelligera*, *C. comta* and *Chrysococcus dokidophorus*.

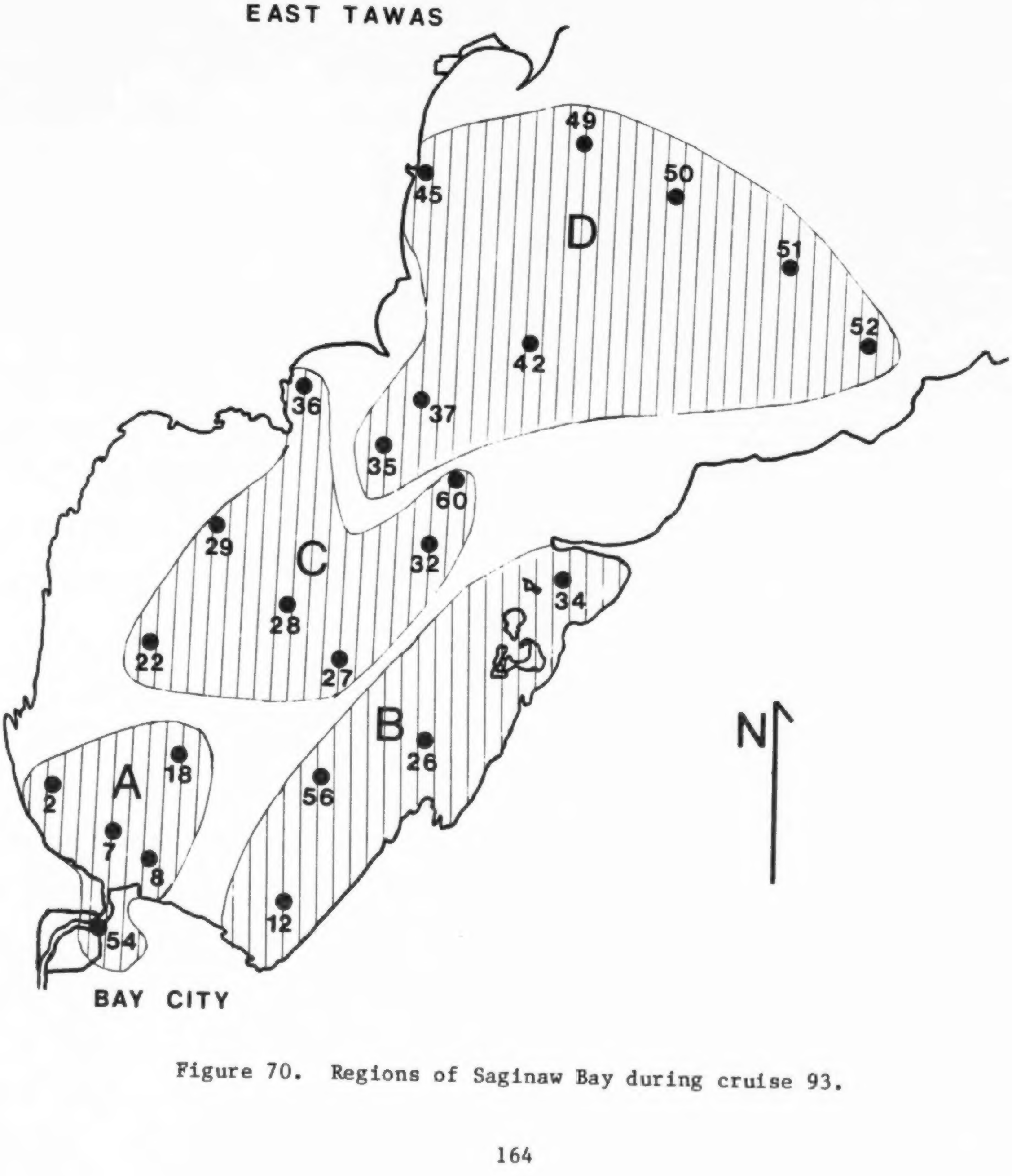
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Figure 70. Regions of Saginaw Bay during cruise 93.

Cruise 94, October 20-24 (Figure 71)

Although the outer row of stations at the Bay-Lake interface was not sampled on this cruise, three regions and two point clusters could still be identified. Wild Fowl Bay again formed a separate point assemblage which was characterized mainly by the blue-green algae *Pelonema* sp., *Schizothrix calcicola*, *Anacystis incerta* and *A. cyanea*. *Synedra filiformis* was again an important component of the phytoplankton assemblage at this station. The River was also distinct, characterized by relatively high levels of the riverine diatoms *Skeletonema potamos* and *Stephanodiscus subtilis*. Region A was characterized by *Monochrysis aphanaster*, *Scenedesmus acutiformis*, *S. spinosus*, *Cyclotella meneghiniana*, *Fragilaria capucina* and *Melosira granulata*. Region B was characterized in part by *Gomphosphaeria lacustris*, *Anacystis cyanea*, *Aphanizomenon gracile* and *Cyclotella meneghiniana*. Region C was not well-defined but did have moderate abundances of algae which did not occur in other regions, including *Cyclotella comensis*, *C. stelligera* and *Rhizosolenia eriensis*.

Cruise 95, November 10-14 (Figure 72)

Four regions were identified. Region A was characterized by the riverine diatoms *Stephanodiscus subtilis*, *S. tenuis* and *Cyclotella pseudostelligera*, and by the blue-green algae *Anacystis cyanea*, *Schizothrix calcicola* and *Pelonema* sp. Region B was characterized by mesotrophic and eurytopic taxa such as *Cyclotella comensis*, *Fragilaria capucina*, *Scenedesmus armatus* var. *boglariensis*, *S. carina* and *Gomphosphaeria lacustris*. Region C was characterized primarily by eurytopic taxa: *Fragilaria capucina*, *Rhizosolenia eriensis*, *Microcoleus vaginatus*, *Ochromonas* spp. and *Chroomonas* spp. Region D

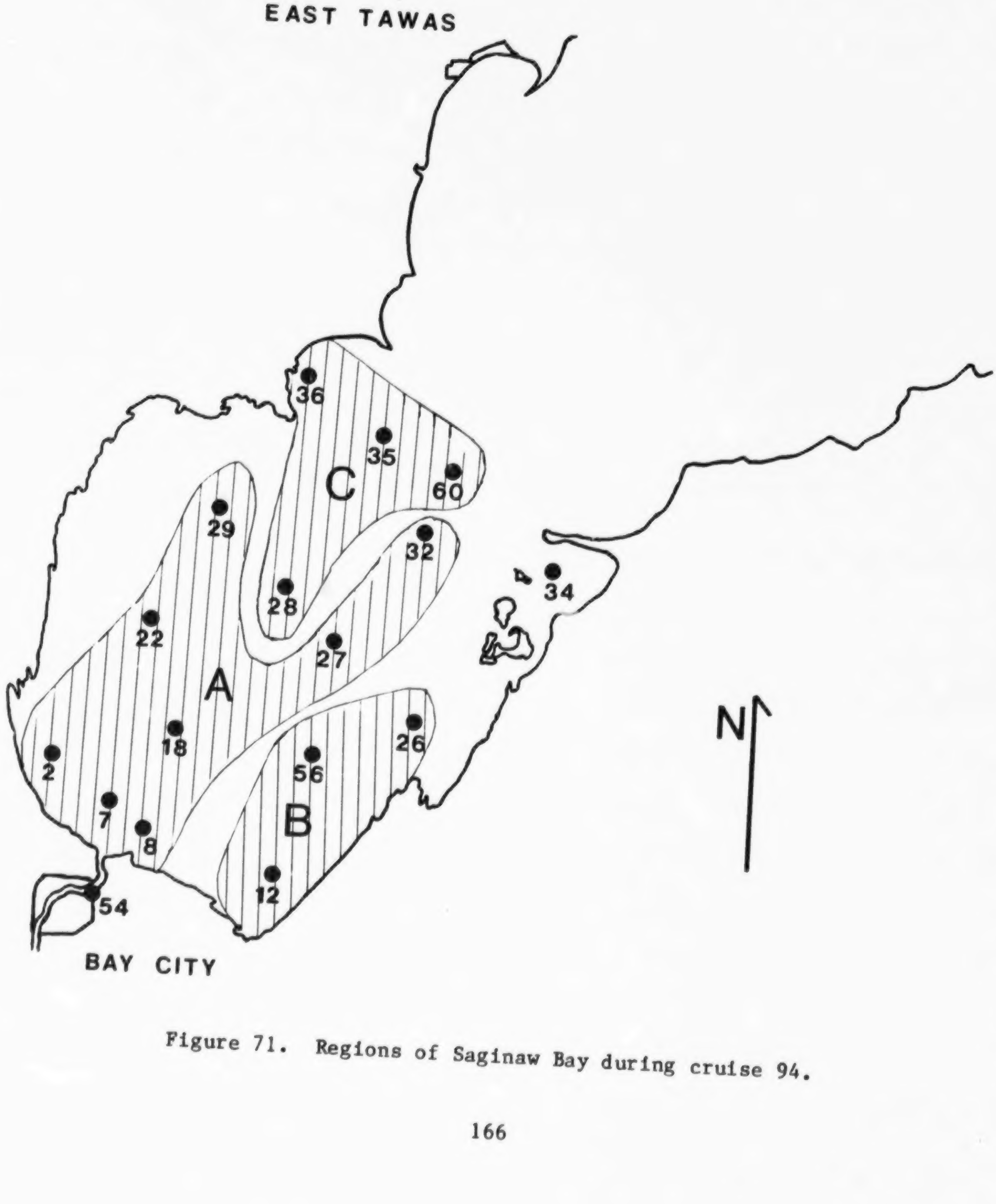
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Figure 71. Regions of Saginaw Bay during cruise 94.

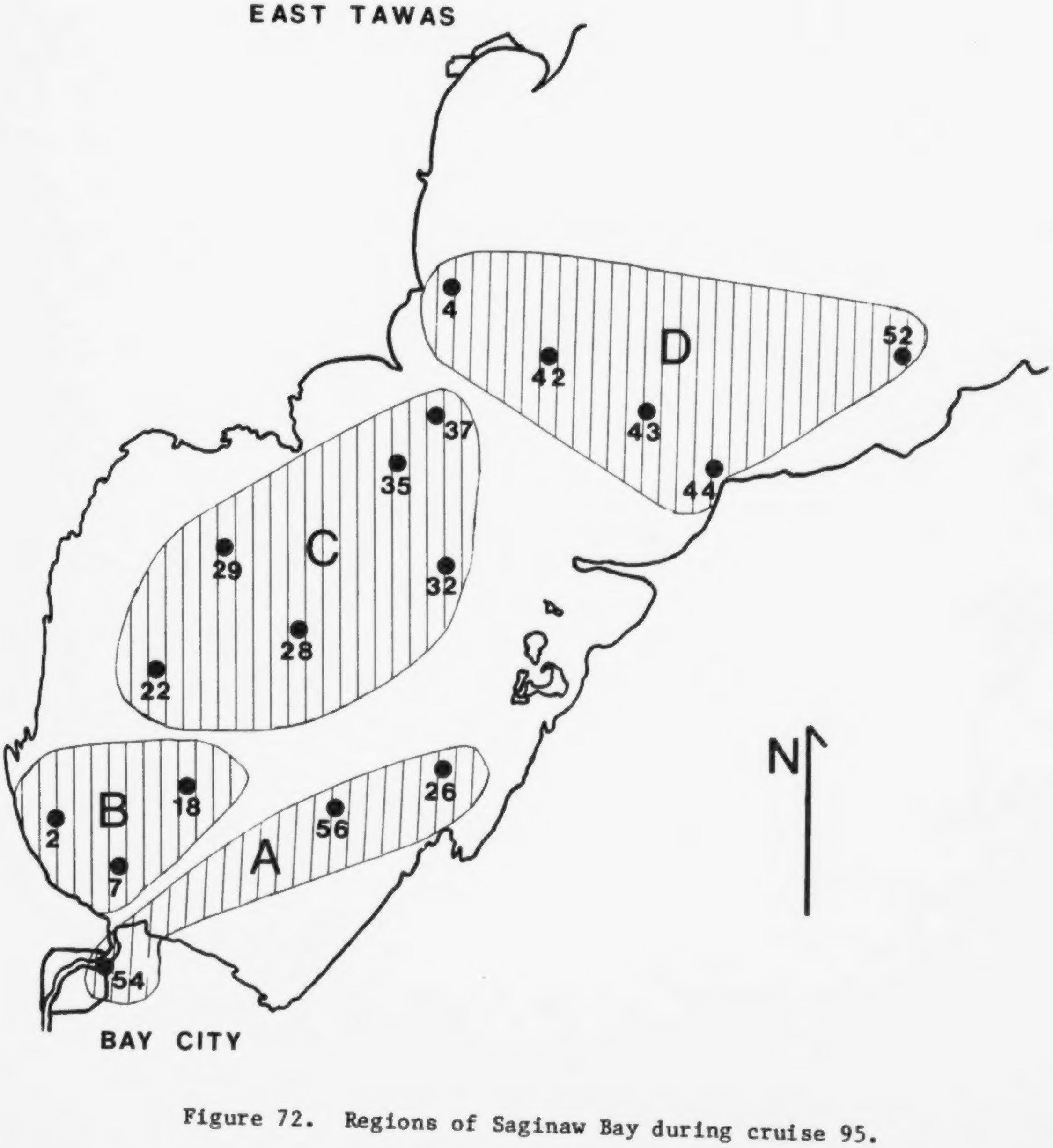
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Figure 72. Regions of Saginaw Bay during cruise 95.

was characterized by the presence of eurytopic and oligotrophic taxa such as *Cyclotella stelligera*, *C. comta*, *Melosira islandica*, *Fragilaria crotonensis* and flagellate #13.

DISCUSSION AND CONCLUSIONS

Water current patterns and entrainment of water masses from Saginaw Bay and Lake Huron apparently controlled phytoplankton distribution and abundance in most of Saginaw Bay during 1980. This general hypothesis concerning processes controlling Bay phytoplankton abundance, is reasonable based on previous studies of Bay current patterns (Danek and Saylor 1977), Bay nutrient chemistry (Smith *et al*. 1977) and Bay phytoplankton distributions (this study). Phytoplankton data indicate that populations normally associated with oligotrophic areas of the Great Lakes enter from Lake Huron along the northwest shore of the Bay. Lake Huron waters mix with nutrient-rich Saginaw River waters in the middle Bay, stimulating increases in phytoplankton abundance levels of certain eurytopic Lake Huron plankton taxa (e.g., *Fragilaria crotonensis*, *Cyclotella comensis* and *Rhodomonas minuta*). The Saginaw River has a distinct flora and provides the initial source or "seed" for several abundant populations of the inner Bay (e.g., *Stephanodiscus subtilis* and *Oscillatoria retzii*). Some of these populations subsequently spread and thrive throughout the Bay (e.g., *O. retzii* and *Melosira granulata*), indicating some mixing of Lake Huron and Saginaw Bay waters. Even so, the Saginaw River-inner Bay phytoplankton community generally maintains its integrity.

Bratzel _et al_. (1977) suggested that phytoplankton populations characteristic of the Bay exit into Lake Huron through the Bay region they designated as Segment 5. This phenomenon, documented with 1974 data by Stoermer and Kreis (1980), appears to have occurred in 1980, although certainly not to as great an extent as in 1974. Cell densities in the western outer Bay (Segment 4) are lower than densities in the eastern outer Bay (Segment 5). However, this difference is not statistically significant (Table 4). Community analyses showed that this is because Segment 5 is a heterogenous collection of stations whose phytoplankton assemblages are generally unrelated.

On the average, all stations along the Bay-Lake interface are clustered together, irregardless of which segment they may occur in. On any one cruise, however, the phytoplankton assemblage at Station 53 may be similar to stations in Segments 2 or 3 in the inner Bay and/or to Station 44 (e.g., Figures 63 and 67). Thus, phytoplankton transport out of the Bay was limited to the extreme nearshore portion of Segment 5 during the periods sampled in 1980.

This point is of interest for the following reasons. Two nearshore stations, 34 in Wild Fowl Bay (Segment 3) and 44 at Oak Point (Segment 5), each have unique phytoplankton assemblages, in the average case, in terms of kinds and amounts of algae present. This indicates a nearshore effect which overwhelms or at least strongly modifies the Saginaw River influence on phytoplankton assemblages in the Bay region which appears to make the most immediate contribution to Lake Huron. It is interesting that Station 44 (Oak Point) is located intermediate to Station 34 (Wild Fowl Bay) and the inner and middle Bay stations along principal component axis II in Figure 60. This suggests that Station 44 is better integrated with the rest of the Bay than is Station 34, an attractive interpretation because Station 44 is not as well protected from offshore Bay waters as is Station 34. Wild Fowl Bay is encompassed by extensive cattail beds, by Sand Point, and by Katechay and Stony Islands. These results imply that elevated cell densities nearshore at the Bay-Lake interface, specifically Station 53, may also occasionally be due to local factors such as runoff and/or nutrient flux from the sediments. At the very least, it may be difficult to distinguish betwen Saginaw River input and nearshore effects on algal transport into Lake Huron.

Application of water quality models require spatial resolution of the Bay. Present divisions of the Bay separate the inner Bay from the outer Bay along a line perpendicular to the Bay long axis (Bratzel *et al*. 1977; Bierman and Dolan 1981). We have some remarks about this division which we do not intend as a criticism. Indeed, model output based on the present divisions seems to fit quite well the actual data previously available for Saginaw Bay (Bierman and Dolan 1981). We only wish to note an apparent phenomenon which occurred in the 1980 data. This may be of interest should steps be taken in the future to refine spatial aspects of Saginaw Bay models.

Phytoplankton data suggest 2 distinct regions of the Bay, the inner Bay (Region A Figure 58) and the outer Bay (Regions B_1-B_3 of Figure 58). Note that a line separating the two regions would be at an angle approximately 45° to the long axis of the Bay. As discussed previously, two stations (34 and 44) belong to neither region, and apparently are not easily integrated with the rest of the Bay. The question that remains is why should the inner and outer Bay be separated at a 45° angle to the Bay long axis? Recall that the River-inner Bay area retains some integrity on the average. Without Lake Huron influence, the River-inner Bay community might well develop along a front perpendicular to the Bay's long axis. However, Lake Huron water enters along the west shore and apparently either deflects the River water mass or mixes with River water in the region north of the River.

The fact that a clear pattern of phytoplankton response to average physical conditions and loading sources to the Bay is an indication of return to a more ecologically stable condition. In a previous study we (Stoermer *et al*. in press) found that large blooms of phytoplankton occurred throughout the lower bay, often without obvious correlation to known loading sources. This situation apparently resulted from overloading of phosphorus to the most directly affected parts of the system. Vollenweider *et al*. (1974) concluded that waters in the inner regions of Saginaw Bay were not nutrient limited, and that variations in phytoplankton production resulted mainly from transient, local meteorological conditions regulating light flux and the sinking velocity of algal populations. Phosphorus overload was also demonstrated by luxury consumption of phosphorus by many algal populations occurring in the Bay during the 1974-1976 period and the transport of phosphorus in the form of polyphosphate bodies out of the Bay to the open waters of Lake Huron (Stoermer *et al*. 1980). Unfortunately the direct studies of phosphorus assimilation were not repeated during the current study, but the fact that polyphosphate bodies are not apparent in cells, as they were previously, and that algal populations appear to show a direct response to loading sources argues that the previous conditions of overload have been mitigated. This should result in a reduction of phosphorus transport to Lake Huron over and above that achieved directly from loading reductions to the Bay, since it is now reasonable to expect that phosphorus entering the Bay will be metabolically processed within the Bay and, as a consequence, subject to normal loss terms.

The effects of phosphorus loading reductions are also evident in qualitative changes in the phytoplankton flora of Saginaw Bay. The most obvious of these is reduction in the abundance and range of distribution of many of the larger species of blue-green algae which form objectionable blooms. These populations had previously been implicated in the production of taste and odor nuisances at water filtration facilities which draw their supplies from Saginaw Bay (Bratzel *et al*. 1977). Equally striking is the virtual elimination of certain diatom populations which, because of their large size, had been a dominant element of phytoplankton biomass in the Bay. As an example, *Actinocyclus normanii* fo. *subsalsa* was found at a limited number of stations and always at low abundance during this study whereas it had been a subdominant previously. This species has been documented to increase dramatically in areas of the Great Lakes which are grossly eutrophied (Hohn 1969) and is considered to be an indicator or gross eutrophication in the Great Lakes system. Similar, although not so dramatic, reductions were noted in the abundance and distribution of other diatom species which have been noted to occur under grossly polluted conditions, such as *Skeletonema* spp., *Thalassiosira* spp., *Stephanodiscus binderanus*, and *S. tenuis*.

One of the unusual aspects of the phytoplankton flora of Saginaw Bay prior to nutrient loading reductions was the abundance of many large-celled diatom species, which are usually restricted to benthic habitats, in the plankton. Included in this group were several species of *Surirella*, *Cymatopleura*, and large, benthic species of the genus *Nitzschia*. During the 1974-1976 study it appeared that the levels of nutrient enrichment in Saginaw Bay allowed these populations, which are usually restricted to the nutrient-rich environment of the sediment-water interface, to successfully exist in plankton assemblages. Although these populations were not present in great numerical abundance, they contributed significantly to the total cell volume of assemblages in Saginaw Bay. Invasion of the plankton by normally benthic populations under conditions of high nutrient loading seems to be a peculiarity of the Laurentian Great Lakes (Stoermer et al. 1974, Holland and Claflin 1975, Stoermer and Stevenson 1980). The only similar situation occurs in the African Rift Lakes, where large species of Surirella are common in the plankton (Hustedt 1949). Such populations were only a very minor component of phytoplankton assemblages sampled during 1980.

Conversely, some populations have increased in abundance in Saginaw Bay. The greatest relative change in abundance is found in some of the smaller species of Cyclotella which are usually components of the summer flora of relatively undisturbed regions for the Laurentian Great Lakes (Stoermer 1978). These species have both increased in abundance and become more widely distributed in Saginaw Bay. Within this group, C. comensis is numerically most important (Figure 23). This species has only recently become an important element of the phytoplankton flora in the Great Lakes. Prior to 1970 it was occasionally found in samples from offshore stations in the upper Great Lakes, but rarely in significant abundance. Since that time it has become a major dominant in the offshore flora of Lake Huron (Stoermer and Kreis 1980) and Lake Michigan (Schelske and Stoermer in publication). Although it is apparently tolerant of a certain degree of nutrient enrichment, and forms atypical summer blooms in the nearshore waters of Lake Huron (Lowe 1976), this species has not been reported from Lake Erie, Lake Ontario, or other grossly disturbed regions of the Great Lakes. In Lake Huron it appears to be particularly efficient at uptake of silica, and usually occurs at stations having relatively high nitrate concentrations (Stoermer and Kreis 1980). It was previously excluded from lower Saginaw Bay, but is an importaat element of assemblages collected in 1980. Species of *Cyclotella* which are less tolerant of eutrophication such as *C. comta* and *C. ocellata* (Stoermer 1978) have increased in abundance in Saginaw Bay, although their distribution is still largely restricted to stations in the outer Bay.

This shift to increased abundance of small-celled species of diatoms is indicative of a general trend toward cells of much less average volume dominating the flora of the Bay. This occurs both through the replacement of larger-celled species by those with smaller average dimensions and through a reduction in the average cell size of eurytopic populations which have remained abundant in the Bay through the period covered by both studies. Since even a small reduction in principle dimensions results in a large reduction in calculated biovolume, the reduction in biovolume of phytoplankton assemblages in the Bay has decreased even more dramatically than have phytoplankton numbers. This change to smaller species probably signals more rapid cycling of nutrient pools in the Bay. Although they were not routinely enumerated because of the requirement for specialized techniques, many samples collected during 1980 contained large numbers of pico-plankton organisms. As is the case in many areas of the oceans, some areas of the Great Lakes are relatively rich in both prokaryotic and eukaryotic photosynthetic organisms in the less than 1 m size range. Although this component of the biota in the Great Lakes has not been well studied, our limited observations suggest that they become most abundant during periods of transition between one nutrient cycling regime and another. An example would be nutrient resupply during the fall mixing period in the upper lakes. It is possible that the relative abundance of such populations in Saginaw Bay reflects the fact that conditions in the Bay are still changing rapidly and the waters of the Bay are undergoing a continuing transition of nutrient regimes. On the basis of our results we consider it likely that the phytoplankton flora of Saginaw Bay will continue to undergo qualitative and quantitative changes even if nutrient loadings are stabilized at the 1980 levels.

The fact that the seasonal succession of phytoplankton in Saginaw Bay was unusual for a temperate water body during 1980 may be another manifestation of this continuing instability. The major departure from previous conditions noted in the 1980 samples is the virtual absence of a spring bloom. In the previous years studied there was a large spring bloom dominated by large species of *Stephanodiscus* and other populations such as *Fragilaria capucina*. During 1980 this spring diatom bloom did not develop and the large biomass contribution, particularly by the large species of *Stephanodiscus* was lacking. Instead, all of the major phytoplankton groups, including diatoms, underwent a continued increase to a seasonal maximum relatively late in the year, then declined during the late fall period to a greater or lesser extent. The reason for this drastic change in successional pattern is not apparent. Nutrient loading measurements made concurrently with this study did not reveal any particularly unusual trends, although spring loadings to the Bay were slightly less than the projected trend (David Dolan, personal communication). Since there are numerous instances of large year to year variations in seasonal succession patterns in eutrophied regions of the Great Lakes (e.g. Chandler and Weeks 1945, Stoermer *et al*. 1974, Nichols *et al*. 1980, Danforth and Ginsberg 1980), it would be useful to determine the mechanism or mechanisms which cause these excursions from the long-term average case.

Although the data presently available to us do not allow a complete analysis, there are plausible mechanisms which could explain the observations and which should be further investigated. The most obvious of these is grazing and consequent modification of nutrient recycle rates. The depressed component of the phytoplankton are diatoms and flagellates which may be grazed most efficiently. It is possible that grazing pressure in the early spring depressed population levels of these species early in the spring and that the recycled nutrients were eventually sequestered by less efficiently grazed green and blue-green species as the season progressed. An alternate hypothesis is that late-season populations were supported by nutrients released from the sediments during the summer. It is possible that both of these mechanisms were operating in 1980 and that there will be a prolonged period of instability until the ecosystem of the Bay adjusts to its new loading regime. This situation is most interesting because most of our examples of population and seasonal succession modification in the Great Lakes come from areas which have been subjected to increased nutrient loadings. It is becoming apparent that reductions in nutrient loading result in equally dramatic changes in species composition and succession but that these changes are not simply a return to previous conditions. An example of this is the apparent continued increase of blue-green algae in Lake Michigan despite reductions in phosphorus loading (Ayers 1978, Danforth and Ginsberg 1980, Ayers and Feldt 1982).

Lake Huron differs from the Lake Michigan case in that it has not progressed as far in eutrophication and in that such a high relative proportion of loadings come from Saginaw Bay and are biologically processed within the Bay. At this point it is clear that the direct contribution of eutrophication tolerant phytoplankton populations from Saginaw Bay to Lake Huron has been reduced. Previously water masses exiting Saginaw Bay carried with them relatively large populations of eutrophication tolerant species (Schelske _et al_. 1974, Stoermer and Kreis 1980). Under average conditions the area most affected by this transport was the Michigan coastal waters south of the Bay, although under certain conditions populations generated within the Bay could be detected north of the Bay and for varying distances into the open lake. In this study we found only two cases where movement of populations beyond the Bay could be expected (Cruise 84, Figure 63; Cruise 90, Figure 67). In all other cases the outer line of stations had assemblages similar to each other and closely related to assemblages in the open lake. In the two cases where transport was apparent, only Station 53 had assemblages similar to.inner Bay stations, which indicates that transport was restricted to nearshore drift. Thus it is quite clear from our results that the direct effects of phosphorus stimulated phytoplankton overproduction on the rest of the Lake Huron ecosystem have been substantially mitigated. There are still cases where populations generated in Saginaw Bay are transported out of the Bay proper, but it is highly doubtful that the extensive injection of eutrophication tolerant populations which occurred under previous conditions (Schelske _et al_. 1974, Stoermer and Kreis 1980) occurs today.

Despite the fact that our results show that there has been substantial water quality improvement in Saginaw Bay, it should be pointed out that some significant problems still remain. In general, the phytoplankton flora of the Bay still contains many populations which are characteristic of eutrophic or disturbed conditions. The seasonal cycle of total phytoplankton abundance (Figure 2) and major physiological group dominance (Figure 3) remains more typical of a hypereutrophic system than of one which is balanced and efficiently productive. As mentioned previously, this may indicate that Saginaw Bay has not yet reached a stable equilibrium with its present loadings, but the conservative conclusion from our results would be that additional loading reductions will be necessary to return the Bay to the most desirable condition.

Results of summary analysis of phytoplankton community structure over the period of this study (Figures 58, 59, 60, and 61) show the direction and extent of perturbation of the phytoplankton community at the stations sampled. As would be expected, Station 54 is a clear outlier. This station is located in the Saginaw River and is only moderately and periodically influenced by conditions in the rest of the Bay. During all sampling periods this station was dominated by phytoplankton populations which characteristically develop under highly disturbed conditions. It is also obvious that this source quite strongly affects a number of stations in the southern Bay (Group A, Figure 58). The phytoplankton flora at these stations is dominated by a mixture of populations derived from the river, eutrophication tolerant lake populations which apparently develop within the region, and some eurytopic populations which also occur at less affected stations.

The great departure of Station 34 and, to a somewhat lesser extent, Station 44 from the flora of the rest of the Bay is perhaps the most interesting result of this study. As will be noted from Figures 60 and 61, these stations differ as much in average phytoplankton composition from the rest of the Bay as Station 54 does. The flora of this area, particularly late in the season, is strongly dominated by blue-green algae and this is the remaining area of the bay where nuisance producing blue-green blooms might be expected to develop. Certain aspects of the phytoplankton flora of this region are highly unusual. For instance, these stations support large blooms of the atypical prokaryote *Pelonema* sp. This organism is apparently achlorotic and most of its close relatives are usually found in highly organically enriched, oxygen depleted environments. *Pelonema* itself has been reported from the plankton of organically enriched lakes where oxygen depletion is not complete (Huber-Pestalozzi 1938). The unique flora of this region of the Saginaw Bay coast leads us to the conclusion that the combination of restricted circulation, loadings transported from the southern part of the Bay, and likely local sources of both nutrient and organic loadings severely effect this region. Unfortunately there is not sufficient information to further analyze this situation.

The rest of the station sampled during this study form an orderly progression from stations with fairly high populations of species tolerant of eutrophic conditions in the southern part of the Bay (Region B_1, Figure 58) to typically oligotrophic populations in the outer Bay Stations. As noted previously, the degree of modification of the phytoplankton flora is skewed by transport of loadings from the southern Bay by the average circulation pattern. It needs to be emphasized that there are considerable differences between these regions. Although these stations and regions appear to be closely clustered in the figures presented, it must be remembered that these analytical techniques scale themselves to the greatest differences in the data set under analysis. In this case the scale of difference is determined by the extremely modified and atypical floras generated at Stations 34 and 54. Although the differences between Regions B_1 and B_3 are small in comparison, they are still significant. To place some perspective on this, although we do not have sufficient data to support a quantitative evaluation, it is almost certainly true that the differences between Region B_1 and B_3 are much larger than between Region B_3 and any other definable region of Lake Huron. In different terms, most phycologists would classify the flora of Region B_1 as characteristic of eutrophic environments and the flora of Region B_3 as more characteristic of oligotrophic environments.

All of this points out that the Saginaw Bay region is probably the ideal laboratory in which to study the problems in the Great Lakes of the 1980's and beyond. It is quite apparent that as control is gained over some of the gross and pervasive problems of the system, such as large point source phosphorus pollution, effective menagement strategies will have to be developed to treat with local specific problems and long term ecosystem effects. Recent studies (Frederick 1981, Harris and Vollenweider 1982) and ordinary common sense indicate that although nutrient control strategies have indeed been successful in reducing gross ecological insults, a much more refined understanding of system processes and much more thoughtfully conceived management strategies will be necessary to return the Great Lakes to a useful and productive, rather than merely tolerable, condition. Our study indicates that the present generation of control measures have begun to reverse a 150 yr history ecosystem degradation in Saginaw Bay. Given the variety of physical conditions present in the system, the known loading characteristics, and the developed data base, it is perhaps the best area in the Great Lakes system to formulate and exercise optimal management strategies.

RECOMMENDATIONS

1. The Wild Fowl Bay region of Saginaw Bay still shows evidence of excessive nutrient loading. Further study should be devoted to this specific region to determine causes of potentially nuisance producing algal blooms.

2. There is substantial evidence that the Saginaw Bay system is still in a transitional state in regards to its response to nutrient loading reduction. Further studies should be conducted to develop a quantitative understanding of processes in ecosystem rehabilitation.

3. Distribution of ecological effects in Saginaw Bay is strongly dependent upon advective transport on both instantaneous and time-averaged scales. These parameters should be included in model segmentation schemes.

4. Our study suggests that there is a step-wise rather than a continuous succession of effects of nutrient loading on phytoplankton species composition. Future research should be devoted to determination of the specific points at which major perturbations occur.

5. Our data suggests that one of the important characteristics in phytoplankton assemblages under recovery conditions is a change from relatively large celled populations to those with less volume per cell. The implications of this for higher levels of the food chain should be investigated.

6. Our study indicates that reduction in nutrient loading does not necessarily result in the phytoplankton flora returning to pre-eutrophication condition. In Saginaw Bay it is evident that many of the taxa now present were not part of the original flora of the bay. The implications of this modified succession should be further investigated.

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APPENDIX 1. SUMMARY OF PHYTOPLANKTON OCCURRENCE IN THE NEAR-SURFACE WATERS OF SAGINAW BAY DURING THE FIELD SEASON OF 1980

	number slides	average density &	% pop.
Undetermined flagellates			
Undetermined colony spp.	2	0.080	0.001
Undetermined cyst	1	0.016	0.000
Undetermined flagellate sp. #10	180	42.606	0.957
Undetermined flagellate sp. #11	10	0.164	0.003
Undetermined flagellate sp. #12	107	6.845	0.184
Undetermined flagellate sp. #13	140	8.724	0.200
Undetermined flagellate sp. #14	21	0.462	0.014
Undetermined flagellate sp. #6	14	0.397	0.013
Undetermined flagellate sp. #7	1	0.008	0.000
Undetermined flagellate sp. #8	12	0.548	0.009
Undetermined flagellate sp. #9	23	1.142	0.026
Undetermined flagellate spp.	269	249.945	3.857
total undetermined (12 categories)		310.937	5.264
Cyanophyta			
Agmenellum quadruplicatum (Menegh.) Bréb.	21	60.343	0.176
Agmenellum spp.	4	6.634	0.022
Anabaena catenula var. *intermedia* Griffiths	9	3.517	0.015
Anabaena flos-aquae (Lyngb.) Bréb.	88	74.388	0.870
Anabaena spp.	13	14.086	0.046
Anabaena subcylindrica Borge	3	3.239	0.022
Anacystis cyanea (Kütz.) Dr. & Dailey	130	629.539	2.392
Anacystis incerta (Lemm.) Dr. & Dailey	168	1639.403	8.061
Anacystis spp.	4	2.777	0.012
Anacystis thermalis (Menegh.) Dr. & Dailey	118	53.153	0.547
Aphanizomenon gracile Lemm.	50	660.343	1.080
Chamaesiphon spp.	1	0.016	0.000
Coelosphaerium spp.	2	0.227	0.002
Dactylococcopsis acicularis Lemm.	1	0.130	0.001
Dactylococcopsis rhaphidioides Hansg.	1	0.454	0.002
Dactylococcopsis smithii Chod. & Chod.	3	0.285	0.005
Gomphosphaeria aponina Kütz.	13	9.400	0.109
Gomphosphaeria lacustris Chod.	128	952.393	5.684
Gomphosphaeria wichurae (Hilse) Dr. & Dailey	25	99.325	0.419
Lyngbya birgei G. M. Smith	2	3.842	0.016
Microcoleus lyngbyaceus (Kütz.) Crouan	8	14.819	0.069
Microcoleus vaginatus (Vauch.) Gom.	28	17.375	0.598
Oscillatoria bornetii (Zuk.) Forti	4	3.908	0.137

APPENDIX 1. (continued).

	number slides	average density	& % pop.
Oscillatoria limnetica Lemm.	17	115.260	0.271
Oscillatoria lutea Ag.	3	10.197	0.068
Oscillatoria retzii Ag.	34	172.585	0.591
Oscillatoria spp.	28	51.803	0.195
Pelonema spp.	54	1177.824	1.484
Plectonema spp.	1	0.779	0.002
Porphyrosiphon spp.	20	52.039	0.165
Raphidiopsis curvata Fritsch & Rich	3	5.904	0.012
Schizothrix calcicola (Ag.) Gom.	99	44.215	0.173
Schizothrix spp.	2	5.353	0.015
Undetermined blue-green colony	1	2.076	0.013
Undetermined blue-green filament sp. #3	13	275.774	0.156
Undetermined blue-green filament sp. #4	25	369.789	0.308
Undetermined blue-green filament	43	119.216	0.365
total blue-green (37 categories)		6652.375	24.104
Chlorophyta			
Actinastrum hantzschii var. *fluviatile* Schroed.	5	5.737	0.021
Ankistrodesmus fusiformis Corda	25	2.417	0.027
Ankistrodesmus gelifactum (Chod.) Bourr.	51	2.898	0.040
Ankistrodesmus gracilis (Reinsch) Kors.	121	11.536	0.113
Ankistrodesmus nannoselene Skuja	2	0.097	0.000
Ankistrodesmus setigerus (Schroed.) G. S. West	165	11.923	0.231
Ankistrodesmus spp.	77	6.053	0.068
Arthrodesmus spp.	1	0.065	0.000
Botryococcus braunii Kütz.	1	0.649	0.005
Characium spp.	1	0.016	0.000
Chlamydomonas spp.	3	0.064	0.003
Chodatella ciliata (Lag.) Chod.	60	23.817	0.222
Chodatella citriformis Snow	6	0.514	0.004
Chodatella quadriseta (Lemm.) G. M. Smith	120	69.771	0.422
Chodatella spp.	2	0.093	0.002
Chodatella subsalsa Lemm.	72	9.882	0.076
Closteriopsis spp.	11	0.702	0.003
Closterium aciculare T. West	30	0.768	0.007
Closterium moniliferum (Bory) Ehrenb.	1	0.016	0.000
Closterium spp.	15	1.095	0.005
Coelastrum cambricum Archer	8	3.392	0.037
Coelastrum microporum Naeg.	152	219.991	1.220
Coelastrum proboscideum Bohlin	2	1.604	0.017
Coelastrum reticulatum (Dang.) Senn	17	14.233	0.120
Coelastrum spp.	12	18.359	0.138

APPENDIX 1. (continued).

	number slides	average density	% pop.
Cosmarium angulosum Bréb.	137	20.019	0.105
Cosmarium bioculatum Bréb.	6	0.132	0.003
Cosmarium depressum var. *planctonicum* Rev.	9	0.151	0.002
Cosmarium geometricum var. *suecicum* Borge	9	0.311	0.005
Cosmarium spp.	66	2.140	0.029
Crucigenia irregularis Wille	3	0.589	0.002
Crucigenia quadrata Morren	57	19.670	0.225
Crucigenia rectangularis (A. Braun) Gay	8	5.470	0.028
Crucigenia spp.	9	1.112	0.013
Crucigenia tetrapedia (Kirch.) West & West	63	27.960	0.106
Crucigenia truncata G. M. Smith	16	13.032	0.039
Dictyosphaerium ehrenbergianum Naeg.	52	33.110	0.139
Dictyosphaerium pulchellum Wood	7	5.756	0.031
Dictyosphaerium spp.	6	0.502	0.013
Dimorphococcus lunatus A. Braun	1	0.195	0.002
Elakatothrix gelatinosa Wille	7	0.345	0.002
Elakatothrix spp.	1	0.260	0.001
Elakatothrix viridis (Snow) Printz	1	0.195	0.000
Eutetramorus spp.	35	3.914	0.107
Franceia droescheri (Lemm.) G. M. Smith	22	0.856	0.010
Franceia ovalis (France) Lemm.	1	0.031	0.000
Gloeocystis planctonica (West & West) Lemm.	145	116.248	0.693
Gloeocystis spp.	62	39.872	0.643
Gloeocystis vesiculosa Naeg.	1	0.273	0.003
Gloeotila pelagica (Nyg.) Skuja	31	239.731	0.463
Gloeotila spp.	12	41.296	0.091
Golenkinia radiata (Chod.) Wille	1	0.065	0.000
Hormidium tribonematoideum Skuja	40	10.545	0.057
Kirchneriella contorta (Schmidle) Bolin	33	6.604	0.028
Kirchneriella lunaris (Kirch.) Moebius	33	6.605	0.037
Kirchneriella lunaris var. *dianae* Bohlin	14	4.683	0.022
Kirchneriella lunaris var. *irregularis* G. M. Smith	48	14.954	0.052
Kirchneriella obesa (W. West) Schmidle	12	1.274	0.009
Kirchneriella obesa var. *aperta* (Teil.) Brunnthaler	11	1.635	0.007
Kirchneriella obesa var. *major* (Bernard) G. M. Smith	3	0.384	0.002
Kirchneriella spp.	134	30.665	0.268
Kirchneriella subsolitaria G. S. West	6	0.281	0.004
Lagerheimia genevensis Chod.	1	0.065	0.001
Lobocystis dichotoma Thompson	20	6.452	0.029
Monoraphidium contortum (Thur.) Kom.-Leg.	10	0.801	0.003
Monoraphidium irregulare (G. M. Smith) Kom.-Leg.	36	2.795	0.021

APPENDIX 1. (continued).

	number slides	average density &	% pop.
Monoraphidium saxatile Kom.-Leg.	2	0.016	0.001
Monoraphidium setiforme (Nyg.) Kom.-Leg.	9	2.903	0.018
Monoraphidium spp.	27	2.262	0.017
Monoraphidium tortile (West & West) Kom.-Leg.	12	1.254	0.007
Mougeotia spp.	91	38.179	0.131
Nephrocytium agardhianum Naeg.	8	0.841	0.018
Nephrocytium limneticum (G. M. Smith) G. M. Smith	5	4.755	0.012
Nephrocytium spp.	10	0.973	0.010
Oocystis parva West & West	1	0.584	0.004
Oocystis spp.	228	168.246	1.252
Pediastrum biradiatum Meyen	25	14.973	0.075
Pediastrum boryanum (Turp.) Menegh.	86	74.036	0.461
Pediastrum duplex Meyen	27	26.617	0.129
Pediastrum duplex var. *clathratum* (A. Braun) Lag.	4	3.989	0.031
Pediastrum duplex var. *cohaerens* Bohlin	16	16.519	0.083
Pediastrum duplex var. *gracilimum* West & West	17	13.462	0.054
Pediastrum duplex var. *rugulosum* Raciborski	5	2.650	0.013
Pediastrum duplex var. *reticulatum* Lag.	3	3.086	0.022
Pediastrum simplex var. *duodenarium* (Bail.) Rabh.	54	30.780	0.163
Pediastrum simplex (Meyen) Lemm.	3	0.908	0.003
Pediastrum spp.	30	8.285	0.038
Pediastrum tetras (Ehrenb.) Ralfs	80	31.348	0.180
Pedinomonas minuta Skuja	1	0.065	0.000
Phacotus lenticularis (Ehrenb.) Stein	15	1.327	0.005
Planktosphaeria gelatinosa G. M. Smith	1	0.125	0.001
Quadrigula closterioides (Bohlin) Printz	1	0.031	0.001
Quadrigula lacustris (Chod.) G. M. Smith	1	0.062	0.001
Scenedesmus acuminatus (Lag.) Chod.	141	118.480	0.473
Scenedesmus acutiformis Schroed.	119	288.034	1.358
Scenedesmus acutus Meyen	4	1.570	0.007
Scenedesmus anomalus var. *acaudatus* Hortob.	4	2.754	0.008
Scenedesmus anomalus (G. M. Smith) Tiff.	3	0.454	0.002
Scenedesmus arcuatus Lemm.	12	2.873	0.018
Scenedesmus armatus Chod.	46	17.968	0.118
Scenedesmus armatus var. *boglariensis* Hortob.	104	73.816	0.391
Scenedesmus bicaudatus (Hansg.) Chod.	13	2.299	0.015
Scenedesmus bicellularis Chod.	105	28.562	0.178
Scenedesmus bijuga (Turp.) Lag.	1	0.125	0.002
Scenedesmus brevispina (G. M. Smith) Chod.	1	0.130	0.000
Scenedesmus carinatus (Lemm.) Chod.	121	96.349	0.509

APPENDIX 1. (continued).

	number slides	average density	% pop.
Scenedesmus circumfusus var. *bicaudatus fo. granulatus* Hortob.		4013.734	0.074
Scenedesmus decorus var. *bicaudato-granulatus* (Hortob.) Uherk.	89	81.449	0.297
Scenedesmus denticulatus var. *linearis fo. costato-granulatus* (Hortob.) Uherk.	37	14.544	0.087
Scenedesmus denticulatus var. *linearis* West	64	29.076	0.152
Scenedesmus denticulatus Lag.	2	0.285	0.003
Scenedesmus dispar Bréb.	5	0.714	0.002
Scenedesmus ecornis (Ralfs) Chod.	9	2.998	0.007
Scenedesmus ecornis var. *disciformis* Chod.	6	1.774	0.006
Scenedesmus flexuosus (Lemm.) Ahlstrom	16	4.927	0.025
Scenedesmus granulatus West & West	46	24.375	0.084
Scenedesmus intermedius Chod.	50	16.618	0.076
Scenedesmus lefevrii var. *semiserratus* Uherk.	98	40.781	0.209
Scenedesmus lefevrii Defl.	116	58.380	0.304
Scenedesmus quadricauda Chod.	198	150.869	0.929
Scenedesmus quadricauda var. *biornatus* Kiss	6	0.359	0.005
Scenedesmus quadricauda var. *longispina* (Chod.) G. M. Smith	5	1.055	0.008
Scenedesmus quadricauda var. *maximus* West & West	24	4.199	0.020
Scenedesmus quadricauda var. *quadrispina* (Chod.) G. M. Smith	1	0.031	0.001
Scenedesmus quadricauda var.?	1	0.031	0.000
Scenedesmus semicristatus Uherk.	7	1.200	0.008
Scenedesmus serratus (Corda) Bohlin	40	6.331	0.030
Scenedesmus spinosus Chod.	219	253.598	1.394
Scenedesmus spp.	214	162.148	1.075
Schroederia spp.	1	0.008	0.000
Selenastrum bibraianum Reinsch	6	1.614	0.008
Selenastrum gracile Reinsch	1	0.260	0.002
Selenastrum minutum (Naeg.) Collins	1	0.031	0.000
Selenastrum spp.	14	2.587	0.010
Sphaerocystis schroeteri Chod.	1	0.062	0.003
Sphaerozosma granulatum Roy & Bissett	3	1.557	0.002
*Sphaerozosma*spp.	1	0.093	0.001
Spondylosium planum (Wolle) West & West	1	0.358	0.004
Staurastrum paradoxum Meyen	17	0.536	0.005
Staurastrum spp.	41	2.228	0.011
Tetraedron caudatum (Corda) Hansg.	80	4.603	0.021
Tetraedron minimum (A. Braun) Hansg.	167	24.357	0.145
Tetraedron muticum (A. Braun) Hansg.	8	0.328	0.002
Tetraedron regulare Kütz.	4	0.120	0.001

APPENDIX 1. (continued).

	number slides	average density &	% pop.
Tetraedron spp.	17	0.797	0.006
Tetraedron trigonum (Naeg.) Hansg.	3	0.161	0.001
Tetrastrum glabrum (Roll) Ahl. & Tiff.	90	31.840	0.172
Tetrastrum heteracanthum (Nord.) Chod.	1	0.062	0.001
Tetrastrum spp.	1	0.031	0.002
Tetrastrum staurogeniaeforme (Schroed.) Lemm.	45	9.470	0.045
Ulothrix amphigranulata Skuja	1	0.140	0.001
Ulothrix spp.	25	3.334	0.046
Ulothrix subtilissima Rabh.	4	0.358	0.012
Undetermined green colonies	178	325.637	1.542
Undetermined green colony sp. #19	6	2.476	0.010
Undetermined green filament	1	0.343	0.006
Undetermined green filament #5	24	15.193	0.168
Undetermined green filaments	12	3.227	0.019
Undetermined green individual	265	248.446	1.921
total green (160 categories)		3698.246	20.847
Bacillariophyta			
Achnanthes affinis Grun.	9	0.182	0.003
Achnanthes biasolettiana (Kütz.) Grun.	2	0.039	0.002
Achnanthes clevei Grun.	2	0.016	0.001
Achnanthes clevei var. *rostrata* Hust.	1	0.065	0.000
Achnanthes exigua Grun.	2	0.016	0.000
Achnanthes lanceolata (Bréb) Grun.	2	0.073	0.001
Achnanthes lanceolata var. *dubia* Grun.	2	0.073	0.001
Achnanthes lanceolata var. *elliptica* Cl.	1	0.008	0.000
Achnanthes lanceolata var. *omissa* Reim.	1	0.008	0.000
Achnanthes lanceolata var. *ninckei* (Guerm. & Mang.) Reim.	5	0.086	0.003
Achnanthes lapponica Hust.	1	0.008	0.000
Achnanthes lauenburgiana Hust.	1	0.016	0.000
Achnanthes lemmermanni Hust.	2	0.073	0.001
Achnanthes linearis (W. Smith) Grun.	2	0.016	0.000
Achnanthes linearis fo. *curta* H. L. Smith	1	0.016	0.001
Achnanthes microcephala (Kütz.) Grun.	1	0.008	0.000
Achnanthes minutissima var. *cryptocephala* Kütz.	20	0.711	0.016
Achnanthes minutissima Grun.	43	1.213	0.034
Achnanthes sp. #1	1	0.016	0.000
Achnanthes sp. #10	1	0.008	0.000
Achnanthes sp. #12	1	0.008	0.000
Achnanthes spp.	32	0.879	0.015

APPENDIX 1. (continued).

	number	average	
	slides	density &	% pop.
Actinocyclus normanii fo. subsalsa (Juhlin-Dannfelt) Hust.	48	6.891	0.029
Amphipleura pellucida (Kütz.) Kütz.	6	0.055	0.002
Amphora ovalis var. *affinis* (Kütz.) V. H.	2	0.024	0.001
Amphora ovalis var. *pediculus* (Kütz.) V. H.	18	0.605	0.009
Amphora ovalis (Kütz.) Kütz.	7	0.095	0.002
Amphora perpusilla Grun.	42	1.662	0.026
Amphora siberica Skv. & Meyer	1	0.065	0.001
Amphora spp.	15	0.538	0.006
Amphora subcostulata Stoermer & Yang	1	0.008	0.000
Amphora thumensis (Mayer) A. Cl.-E.	1	0.016	0.001
Anomoeoneis spp.	1	0.023	0.000
Anomoeoneis vitrea (Grun.) Ross	3	0.031	0.001
Asterionella formosa Hass.	178	42.233	1.022
Cocconeis diminuta Pant.	1	0.016	0.000
Cocconeis pediculus Ehrenb.	1	0.008	0.000
Cocconeis placentula var. *euglypta* (Ehrenb.) Cl.	2	0.016	0.001
Cocconeis placentula var. *lineata* (Ehrenb.) V. H.	1	0.065	0.000
Cocconeis sp. #2	6	0.127	0.002
Cocconeis spp.	1	0.016	0.001
Cyclotella antiqua W. Smith	2	0.023	0.000
Cyclotella atomus Hust.	34	36.952	0.158
Cyclotella comensis Grun.	252	917.017	10.710
Cyclotella comta (Ehrenb.) Kütz.	72	2.611	0.065
Cyclotella cryptica Reimann, Lewin & Guillard	6	1.548	0.007
Cyclotella kutzingiana Thwaites	8	0.070	0.002
Cyclotella meneghiniana Kütz.	66	131.049	0.446
Cyclotella michiganiana Skv.	47	1.068	0.027
Cyclotella ocellata Pant.	101	5.717	0.246
Cyclotella operculata (Ag.) Kütz.	7	0.103	0.003
Cyclotella pseudostelligera Hust.	117	38.604	0.248
Cyclotella sp. #6	2	0.319	0.008
Cyclotella sp. auxospore	29	0.393	0.011
Cyclotella spp.	21	1.747	0.015
Cyclotella stelligera (Cl. & Grun.) V. H.	122	8.224	0.247
Cyclotella stelligera auxospore	1	0.008	0.000
Cymatopleura elliptica (Bréb & Godey) W. Smith	7	0.192	0.001
Cymatopleura solea (Bréb & Godey) W. Smith	16	0.227	0.006
Cymbella cistula (Ehrenb.) Kirch.	1	0.008	0.000
Cymbella inaequalis Ross	1	0.016	0.000
Cymbella microcephala Grun.	59	1.462	0.040
Cymbella minuta Hilse	7	0.174	0.003

APPENDIX 1. (continued).

	number	average	
	slides	density &	% pop.
Cymbella minuta var. *silesiaca* (Bleisch & Rabh.) Reim.	1	0.008	0.000
Cymbella parvula Krasske	1	0.031	0.000
Cymbella prostrata var. *auerswaldii* (Rabh.) Reim.	4	0.064	0.001
Cymbella prostrata (Berk.) Cl.	1	0.008	0.000
Cymbella spp.	11	0.302	0.004
Denticula spp.	1	0.016	0.000
Denticula tenuis var. *crassula* (Naeg. & Kütz.) West & West	7	0.086	0.002
Diatoma ehrenbergii Kütz.	1	0.016	0.000
Diatoma spp.	2	0.016	0.001
Diatoma tenue Ag.	5	0.120	0.005
Diatoma tenue var. *elongatum* Lyngb.	71	22.650	0.397
Diatoma vulgare Bory	3	0.138	0.003
Diploneis boldtiana Cl.	1	0.016	0.000
Diploneis parma Cl.	2	0.016	0.000
Diploneis spp.	1	0.031	0.001
Entomoneis ornata (J. W. Bail.) Reim.	10	0.231	0.003
Eucocconeis spp.	5	0.470	0.002
Fragilaria brevistriata Grun.	48	7.870	0.059
Fragilaria brevistriata var. *inflata* (Pant.) Hust.	34	4.805	0.023
Fragilaria capucina Desm.	211	1797.731	14.185
Fragilaria construens (Ehrenb.) Grun.	116	37.414	0.346
Fragilaria construens var. *binodis* (Ehrenb.) Grun.	2	0.039	0.000
Fragilaria construens var. *minuta* Temp. & Per	45	2.002	0.029
Fragilaria construens var. *subsalina* Hust.	1	0.202	0.003
Fragilaria construens var. *venter* (Ehrenb.) Grun.	63	16.120	0.070
Fragilaria crotonensis Kitton	219	154.444	2.234
Fragilaria intermedia Grun.	4	0.335	0.010
Fragilaria intermedia var. *fallax* (Grun.) A. Cl.	5	0.319	0.008
Fragilaria leptostauron (Ehrenb.) Hust.	15	1.398	0.033
Fragilaria pinnata var. *intercedens* (Grun.) Hust.	2	0.693	0.015
Fragilaria pinnata var. *lancettula* (Schum.) Hust.	9	0.445	0.005
Fragilaria pinnata Ehrenb.	159	36.044	0.403
Fragilaria sp. #18	2	0.023	0.000
Fragilaria sp. #2	1	0.008	0.001
Fragilaria spp.	43	3.058	0.052
Fragilaria vaucheriae (Kütz.) Peters	33	1.117	0.019

APPENDIX 1. (continued).

	number slides	average density &	% pop.
Fragilaria vaucheriae var. *capitellata* (Grun.) Patr.			
Fragilaria vaucheriae var. *lanceolata* A. Mayer	9	2.883	0.005
Fragilaria vaucheriae var. *truncata* (Grev.) Grun.	3	0.550	0.001
Gomphonema angustatum (Kütz.) Rabh.	2	0.032	0.002
Gomphonema olivaceum (Lyngb.) Kütz.	1	0.016	0.001
Gomphonema parvulum (Kütz.) Kütz.	4	0.040	0.002
Gomphonema spp.	2	0.073	0.001
Gyrosigma acuminatum (Kütz.) Rabh.	3	0.039	0.001
Gyrosigma sciotense (Sullivant & Wormley) Cl.	1	0.016	0.000
Melosira distans var. *alpigena* Grun.	2	0.016	0.000
Melosira granulata fo. *spiralis* Grun.	33	4.778	0.028
Melosira granulata var. *angustissima* O. Müll.	1	0.195	0.000
Melosira granulata (Ehrenb.) Ralfs	8	4.175	0.035
Melosira islandica O. Müll.	113	73.796	0.395
Melosira italica subsp. *subarctica* O. Müll.	31	2.005	0.064
Melosira varians Ag.	12	0.413	0.014
Meridion circulare (Grev.) Ag.	2	0.389	0.002
Navicula acceptata Hust.	1	0.049	0.005
Navicula anglica var. *subsalsa* (Grun.) Cl.	1	0.008	0.000
Navicula aurora Sov.	1	0.008	0.000
Navicula bacillum Ehrenb.	1	0.008	0.000
Navicula capitata Ehrenb.	1	0.008	0.000
Navicula capitata var. *luneburgensis* (Grun.) Patr.	3	0.032	0.002
Navicula cryptocephala var. *intermedia* Grun.	1	0.065	0.001
Navicula cryptocephala var. *veneta* (Kütz.) Rabh.	3	0.089	0.002
Navicula cryptocephala Kütz.	15	0.467	0.006
Navicula exiguiformis Hust.	10	0.491	0.003
Navicula graciloides A. Mayer	1	0.008	0.000
Navicula gregaria Donk.	1	0.032	0.000
Navicula heufleri var. *leptocephala* (Bréb) Patr.	13	1.092	0.010
Navicula lanceolata (Ag.) Kütz.	1	0.032	0.000
Navicula luzonensis Hust.	3	0.024	0.002
Navicula menisculus var. *upsaliensis* Grun.	2	0.097	0.001
Navicula minima Grun.	1	0.008	0.000
Navicula monoculata Hust.	1	0.016	0.000
Navicula paludosa Hust.	1	0.008	0.000
Navicula pelliculosa (Bréb) Hilse	2	0.065	0.000
Navicula pupula Kütz.	1	0.065	0.000
Navicula radiosa var. *tenella* (Bréb) Grun.	5	0.063	0.002
Navicula radiosa Kütz.	16	0.391	0.004
	5	0.070	0.000

APPENDIX 1. (continued).

	number	average	
	slides	density &	% pop.
Navicula salinarum Grun.	1	0.008	0.001
Navicula scutelloides W. Smith	2	0.097	0.001
Navicula seminuloides Hust.	2	0.080	0.001
Navicula seminulum Grun.	2	0.024	0.001
Navicula sp. #81	1	0.065	0.000
Navicula sp. #82	2	0.039	0.000
Navicula sp. #84	1	0.016	0.000
Navicula spp.	50	2.352	0.036
Navicula tripunctata var. *cuneata* (Lauby) Stoerm. & Yang	2	0.073	0.001
Navicula tripunctata (O. Müll.) Bory	3	0.138	0.001
Navicula ventralis fo. *simplex* (Hust.) Hust.	1	0.016	0.001
Navicula viridula var. *avenacea* (Bréb.) V. H.	2	0.130	0.001
Nitzschia acicularioides Arch.	3	0.170	0.001
Nitzschia acicularis (Kütz.) W. Smith	44	3.908	0.036
Nitzschia acidoclinata Lange-Bertalot	1	0.130	0.001
Nitzschia acuta Hantz.	8	0.094	0.004
Nitzschia amphibia Grun.	3	0.089	0.001
Nitzschia angustata (W. Smith) Grun.	5	0.186	0.000
Nitzschia angustata var. *acuta* Grun.	17	0.673	0.005
Nitzschia brevirostris Hust.	1	0.008	0.000
Nitzschia capitellata Hust.	5	0.169	0.001
Nitzschia confini Hust.	9	0.172	0.005
Nitzschia dissipata (Kütz.) Grun.	18	0.352	0.009
Nitzschia dissipata var. *media* (Hantz.) Grun.	4	0.087	0.003
Nitzschia fonticola Grun.	24	0.739	0.009
Nitzschia fonticola var. *pelagica* Hust.	1	0.032	0.000
Nitzschia frustulum var. *tenella* Grun. *ex* V. H.	5	0.186	0.001
Nitzschia graciliformis Lange-Bertalot & Simonsen	7	0.149	0.005
Nitzschia gracilis Hantz.	40	1.051	0.025
Nitzschia holsatica Hust.	2	0.300	0.001
Nitzschia kutzingiana Hilse	69	2.425	0.037
Nitzschia lauenbergiana Hust.	1	0.008	0.000
Nitzschia longissima var. *reversa* Grun.	2	0.195	0.000
Nitzschia palea (Kütz.) W. Smith	32	0.758	0.022
Nitzschia palea var. *debilis* (Kütz.) Grun.	16	1.740	0.006
Nitzschia palea var. *tenuirostris* Hust.	3	0.178	0.000
Nitzschia paleacea Grun.	4	0.031	0.001
Nitzschia planctonica Hust.	1	0.031	0.000
Nitzschia pumila Hust.	2	0.162	0.001
Nitzschia pura Hust.	16	0.706	0.014
Nitzschia recta Hantz.	4	0.056	0.001
Nitzschia romana Grun.	3	0.258	0.002

APPENDIX 1. (continued).

	number	average	
	slides	density &	% pop.
Nitzschia sinuata var. *tabellaria* (Grun.) Grun.	1	0.031	0.000
Nitzschia sp. #1	19	0.733	0.004
Nitzschia sp. #10	5	0.241	0.002
Nitzschia sp. #15	6	1.071	0.005
Nitzschia sp. #17	1	0.065	0.000
Nitzschia sp. #2	1	0.016	0.000
Nitzschia sp. #32	13	0.210	0.010
Nitzschia sp. #38	1	0.008	0.000
Nitzschia sp. #40	136	11.866	0.144
Nitzschia sp. #6	3	0.160	0.003
Nitzschia sp. #7	1	0.130	0.000
Nitzschia sp. #9	14	0.409	0.003
Nitzschia spiculoides Hust.	22	1.000	0.012
Nitzschia spiculum Hust.	1	0.041	0.001
Nitzschia spp.	182	19.026	0.252
Nitzschia subacicularis Hust.	7	0.376	0.003
Nitzschia subcapitellata Hust.	3	0.130	0.000
Nitzschia sublinearis Hust.	5	0.364	0.002
Nitzschia tryblionella var. *debilis* (Arnott) Mayer	9	0.222	0.004
Opephora martyi Herib.	2	0.080	0.000
Rhizosolenia eriensis H. L. Smith	125	7.049	0.183
Rhizosolenia gracilis H. L. Smith	96	6.956	0.225
Rhizosolenia spp.	47	3.818	0.034
Rhizosolenia statospore	1	0.032	0.000
Rhoicosphenia curvata (Kütz.) Grun.	3	0.105	0.001
Rhoicosphenia sp.	1	0.008	0.000
Skeletonema potamos (Weber) Hasle	31	20.958	0.123
Skeletonema spp.	5	0.994	0.007
Stephanodiscus alpinus Hust.	134	11.882	0.197
Stephanodiscus binderanus (Kütz.) Krieg.	65	27.412	0.435
Stephanodiscus hantzschii Grun.	86	13.198	0.253
Stephanodiscus minutus Grun. *ex* Cl. & Möll.	94	10.722	0.099
Stephanodiscus niagarae Ehrenb.	82	3.195	0.032
Stephanodiscus sp. #10	42	4.496	0.031
Stephanodiscus sp. #5	10	0.395	0.006
Stephanodiscus spp.	67	19.386	0.118
Stephanodiscus subtilis (Van Goor) A. Cl.	160	82.658	0.769
Stephanodiscus tenuis Hust.	96	66.465	0.534
Surirella angusta Kütz.	3	0.031	0.001
Surirella ovata Kütz.	17	0.454	0.012
Surirella ovata var. *pinnata* (W. Smith) Hust.	16	0.552	0.013
Surirella spp.	11	0.208	0.003
Surirella suecica Grun. *ex* V. H.	10	0.574	0.003

APPENDIX 1. (continued).

	number slides	average density	& % pop.
Synedra cyclopum Brutschy	7	0.078	0.002
Synedra delicatissima var. *angustissima* Grun.	43	0.895	0.023
Synedra filiformis var. *exilis* A. Cl.	25	0.928	0.025
Synedra filiformis Grun.	180	49.287	0.764
Synedra minuscula Grun.	20	0.616	0.020
Synedra ostenfeldii (Krieger) A. Cl.	61	2.131	0.059
Synedra parasitica (W. Smith) Hust.	2	0.078	0.001
Synedra rumpens Kütz.	1	0.016	0.000
Synedra rumpens var. *familiaris* (Kütz.) Hust.	1	0.023	0.001
Synedra rumpens var. *fragilarioides* Grun. *ex* V. H.	3	0.436	0.014
Synedra spp.	44	2.770	0.030
Synedra ulna var. *chaseana* Thomas	10	0.133	0.005
Synedra ulna (Nitz.) Ehrenb.	7	0.291	0.004
Tabellaria fenestrata (Lyngb.) Kütz.	91	15.473	0.514
Tabellaria flocculosa var. *geniculata* (Cl.-E.) Knudson	1	0.101	0.010
Tabellaria flocculosa (Roth) Kütz.	9	0.409	0.023
Tabellaria flocculosa var. *linearis* Koppen	149	30.804	0.742
Thalassiosira spp.	7	2.790	0.013
Undetermined centric diatom spp.	73	15.836	0.106
Undetermined pennate diatom	13	0.410	0.004
total diatoms (247 categories)		3843.911	38.056
Chrysophyta			
Arachnochloris reticulata (Pasch.) Bourr.	1	0.016	0.000
Chrysidiastrum catenatum Ltb.	1	0.008	0.000
Chrysococcus dokidophorus Pasch.	38	0.811	0.037
Chrysococcus rufescens Klebs	20	0.410	0.013
Chrysococcus spp.	19	1.811	0.045
Chrysophycean cyst	65	2.090	0.042
Chrysosphaerella longispina Ltb.	41	7.445	0.136
Dinobryon cylindricum Imh.	9	2.912	0.104
Dinobryon cyst	62	2.916	0.080
Dinobryon divergens Imh.	12	1.760	0.048
Dinobryon sociale Ehrenb.	6	2.478	0.015
Dinobryon spp.	144	32.585	0.833
Kephyrion spirale (Lack.) Conr.	2	0.080	0.001
Mallomonas alpina Pasch.	102	4.525	0.046
Mallomonas elongata Rev.	9	0.103	0.003
Mallomonas pseudocoronata Prescott	49	1.557	0.016
Mallomonas sp. #3	1	0.008	0.000

APPENDIX 1. (continued).

	number slides	average density	& % pop.
Mallomonas spp.	15	0.357	0.014
Mallomonas statospore	17	0.244	0.006
Monochrysis aphanaster Skuja	186	11.557	0.255
Ochromonas sp. #3	2	0.078	0.001
Ochromonas spp.	260	247.193	3.183
Rhizochrysis limnetica G. M. Smith	1	0.016	0.000
Spiniferomonas spp.	171	16.262	0.355
Synura spp.	1	0.311	0.003
Synura uvella Ehrenb.	4	0.358	0.010
Tribonema spp.	11	1.361	0.016
Tribonema subtilissimum Pasch.	3	0.171	0.003
Undetermined colonial chrysophyte	1	0.973	0.002
Undetermined individual chrysophyte	6	0.240	0.003
total chrysophytes (30 categories)		340.871	5.271
Cryptophyta			
Chroomonas spp.	265	126.813	2.031
Cryptomonas erosa Ehrenb.	31	2.674	0.023
Cryptomonas gracilis Skuja	7	0.407	0.004
Cryptomonas marssonii Skuja	57	3.007	0.038
Cryptomonas ovata Ehrenb.	214	38.607	0.368
Cryptomonas pyrenoidifera Geitler	19	0.889	0.012
Cryptomonas rostratiformis Skuja	45	1.792	0.014
Cryptomonas sp. #3	118	14.938	0.120
Cryptomonas spp.	198	34.478	0.417
Rhodomonas minuta Skuja	260	231.573	3.041
Rhodomonas spp.	47	14.460	0.152
total cryptomonads (10 categories)		469.232	6.217
Pyrrhophyta			
Ceratium hirundinella (Müll.) Shrank	27	0.631	0.005
Dinoflagellate cyst	8	0.165	0.002
Glenodinium bernardinense Chod. & Zend.	5	0.243	0.006
Gymnodinium helveticum Penard	13	0.188	0.005
Gymnodinium ordinatum Skuja	50	1.460	0.026
Gymnodinium spp.	45	1.737	0.031
Peridinium achromaticum Levander	10	1.012	0.013
Peridinium spp.	23	0.503	0.013
Unidentified dinoflagellate spp.	168	8.842	0.132

APPENDIX 1. (continued).

	number slides	average density	% pop.
total dinoflagellates (10 categories)			
		14.789	0.234
Euglenophyta			
Euglena acus Ehrenb.			
Euglena spp.	1	0.130	0.001
Phacus spp.	5	0.213	0.002
total euglenoids (3 categories)	1	0.032	0.000
		0.376	0.003